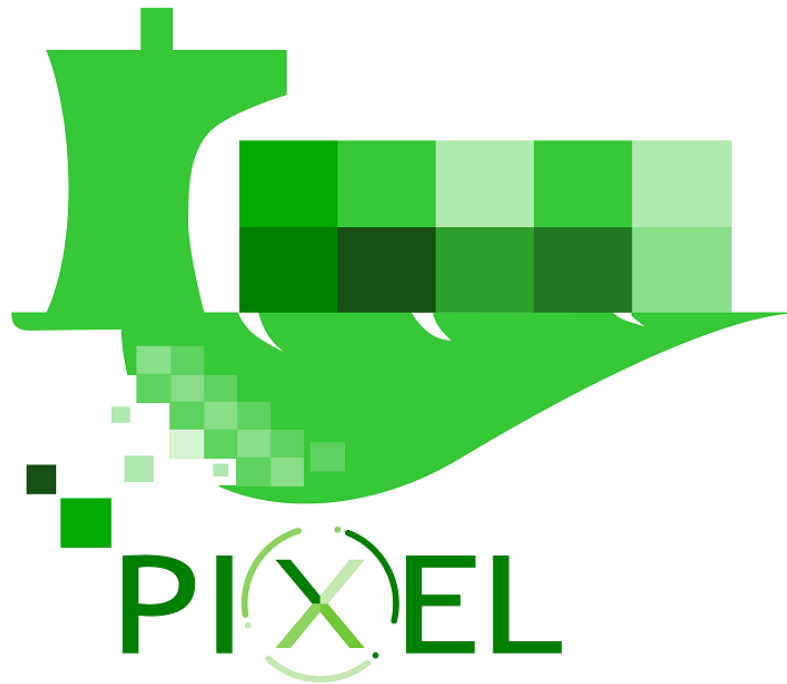


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## D4.2 – PIXEL Models v2

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<b>Version</b>	2.0	<b>Status</b>	Final
<b>Description</b>	This deliverable is focused on PIXEL Models. It includes a description of the overall methodology for the environmental management of port and a description of the models, algorithms and numerical methods for each model. This is the second version of the deliverable updating D4.1.		
<b>Work Package</b>	WP4		

## Authors

Name	Partner	e-mail
Ignacio Lacalle	P01 – UPV	<a href="mailto:iglaub@upv.es">iglaub@upv.es</a>
Benjamin Molina	P01 – UPV	<a href="mailto:benmomo@upvnet.upv.es">benmomo@upvnet.upv.es</a>
Gilda De Marco	P04 – INSIEL	<a href="mailto:gilda.demarco@insiel.it">gilda.demarco@insiel.it</a>
Paolo Casoto	P04 – INSIEL	<a href="mailto:paolo.casoto@gmail.com">paolo.casoto@gmail.com</a>
Devescovi Manuel	P04 – INSIEL	<a href="mailto:manuel.devescovi@insiel.it">manuel.devescovi@insiel.it</a>
Charles Garnier	P05 – CATIE	<a href="mailto:c.garnier@catie.fr">c.garnier@catie.fr</a>
Erwan Simon	P05 – CATIE	<a href="mailto:e.simon@catie.fr">e.simon@catie.fr</a>
Deborah Mille	P07 – CREO	<a href="mailto:mille@creocean.fr">mille@creocean.fr</a>
Luka Traven	P08 – MEDRI	<a href="mailto:luka.traven@medri.uniri.hr">luka.traven@medri.uniri.hr</a>
Igor Kegalj	P08 – MEDRI	<a href="mailto:igor.kegalj@medri.uniri.hr">igor.kegalj@medri.uniri.hr</a>
Stjepan Piličić	P08 – MEDRI	<a href="mailto:stjepan.pilicic@medri.uniri.hr">stjepan.pilicic@medri.uniri.hr</a>
Teodora Milosevic	P08 – MEDRI	<a href="mailto:teodoramilosevic1@gmail.com">teodoramilosevic1@gmail.com</a>
Tamara Corsano	P09 – SDAG	<a href="mailto:t.corsano@sdag.it">t.corsano@sdag.it</a>
Andrea Chinese	P09 – SDAG	<a href="mailto:a.chinese@sdag.it">a.chinese@sdag.it</a>
Cinzia Ninzatti	P09 – SDAG	<a href="mailto:c.ninzatti@sdag.it">c.ninzatti@sdag.it</a>
Stefano Bevilacqua	P12 – ASPM	<a href="mailto:s.bevilacqua@monfalconeport.it">s.bevilacqua@monfalconeport.it</a>
Leonidas Pitsikas	P14 – IPEOPLE	<a href="mailto:lpitsikas@peoplethinkbeyond.com">lpitsikas@peoplethinkbeyond.com</a>

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## Abstract

Ports activities undeniably have an impact on their environment, the city and citizens living nearby. To have a better understanding of these impacts, the ports of the future will require tools allowing suitable modelling, simulation and data analysis. Based on the reality of port activities and available data, the PIXEL partners have developed and/or integrated models in order to provide ports with these useful tools. This will help them to have a better understanding of their environmental impacts. These models are focused on:

- (i) Modelling of the supply chain and port's activities (type of machine, duration of use, position in the port) to enable us to build activity scenarios that are used to identify the energy sources, local emissions of pollutants but also to estimate the flow of cargoes entering or leaving the port.
- (ii) Modelling of consumption and energy production of the port with the aim of moving towards green energy production. For operational actors in ports, energy efficiency is an important issue, both from the environmental and economic perspectives. In order to optimize the energy flows inside the port, a prerequisite is to manage and quantify energy consumption and production in the context of complex industrial processes.
- (iii) Modelling of congestion of multi-modal transport networks to reduce the impact of port traffic on the network. The model will help to understand if a different traffic management has a positive impact on congestions issues, citizens risk on the road and environmental impacts.
- (iv) Modelling of environmental pollution of the port to reduce the environmental impacts of the port on the city and its citizens. These simulations can assist the port manager/operator in the decision-making process in order to optimize various activities within the port and minimize their impact on the environment.

All of these models are described, in this report that aims to summarize the result of tasks T4.1, T4.2, T4.3 and T4.4 of Work Package 4 and provide an overall description of PIXEL's models. It gives a full technical description of port-operation to model and provides elements related with model accuracy, scope and how to have a concrete implementation and integration of the models.

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## List of acronyms

Acronym	Explanation
<b>ADR</b>	Accord for Dangerous goods by Road
<b>AIS</b>	Automatic Identification System
<b>API</b>	Application Programming Interface
<b>ASPM</b>	Azienda Speciale Porto di Monfalcone
<b>BTEX</b>	Benzene, toluene, and the three xylene isomers
<b>CCS</b>	Cargo Community System
<b>CMSAF</b>	Climate Monitoring Satellite Application Facility
<b>EMP</b>	Environmental Management Plan
<b>EPMS</b>	Electrical Power Management Systems
<b>ESPO</b>	European Sea Ports Organisation
<b>FAL</b>	Facilitation of International Maritime Traffic
<b>GCS</b>	Gate Control System
<b>GHG</b>	Green House Gases
<b>GloMEEP</b>	Global Maritime Energy Efficiency Partnerships
<b>GPMB</b>	Grand Port Maritime de Bordeaux - Port of Bordeaux
<b>IAPH</b>	International Association of Ports and Harbors
<b>IMO</b>	International Maritime Organization
<b>INSIEL</b>	INformatica per Il SEstem degli Enti Locali
<b>ISO</b>	International Organization for Standardization
<b>JSON</b>	JavaScript Object Notation
<b>KPI</b>	Key Performance Indicator
<b>LSFO</b>	Low Sulphur Fuel Oil
<b>MDO</b>	Marine Diesel Oil
<b>NoMEPorts</b>	Noise Management in European Ports
<b>NREL</b>	National Renewable Energy Laboratory
<b>NSRD</b>	National Solar Radiation Database
<b>NTUA</b>	National Technical University of Athens
<b>PCS</b>	Port Community System
<b>PEI</b>	Port Environmental Index
<b>PERS</b>	Port Environmental Review System
<b>PIXEL</b>	Port IoT for Environmental Leverage
<b>PM<sub>10</sub></b>	Particulate Matter 10um
<b>PM<sub>2.5</sub></b>	Particulate Matter 2.5um
<b>PMIS</b>	Port Management Information System
<b>PPAgIS</b>	Piraeus Port Authority SA
<b>PVSIG</b>	PHotovoltaic Geographical Information System
<b>Ro-Ro</b>	Roll On-Roll Off
<b>SAM</b>	System Advisor Model
<b>SCADA</b>	Supervisory Control and Data Acquisition
<b>SDAG</b>	Stazioni Doganali Autoportuali Gorizia

<b>SDK</b>	Software Development Kit
<b>SDM</b>	Self-Diagnosis Method
<b>SILI</b>	Sistema Informativo Logistico Integrato (Integrated Logistic Informed System), a system provided by Regione Friuli Venezia Giulia and managed by Insiel to monitor and authorize entries to the Ports of Monfalcone and Trieste; it also monitors dangerous goods flows along the regional motorway network
<b>SQL</b>	Structured Query Language
<b>TEU</b>	Twenty-foot equivalent unit
<b>THPA</b>	Thessaloniki Port Authority
<b>TMS</b>	Traffic Management Centre
<b>UI</b>	User Interface
<b>WP</b>	Work Package

# 1. About this document

This document aims to present the models developed or used in WP4, that will be integrated in the PIXEL platform in WP6 and test and validate in real conditions in WP7. These models deal with issues of energy consumption, multimodal transport and environmental pollution in order to improve the environmental management of ports. Since PIXEL is focused on the port reality, these models are based on the needs expressed by the 4 ports participating as partners of the Consortium of the project. However, PIXEL also has a generalist scope thus modelling is addressed in a way that models can be (with the less possible changes) employed by other ports to improve their environmental management.

In this document, we present and report about models that have been developed. We provide a complete description of PIXEL models: in D4.2 readers will have *a description of the overall methodology for the environmental management of port and a description of the models, algorithms and numerical methods for each model.*

This document also provides requirements for the integration of PIXEL models in the PIXEL Operational Tools (WP6) as well as for the real test and integration phase of PIXEL models within ports (WP7).

## 1.1. Deliverable context

*Table 1: Deliverable context*

Keywords	Lead Editor
<b>Objectives</b>	<p><b><i>Objective 4: Model and simulate port-operation processes for automated operation</i></b></p> <p>This deliverable provides the specifications of the PIXEL models and data analysis. The overall methodology to achieve the modelling of port-operation processes and environmental management are described.</p> <p><b><i>Objective 5: Develop predictive algorithms</i></b></p> <p>By describing modelling needs of ports and by setting up model, this deliverable contributes to identify candidates for predictive algorithms that have the potential of significantly increase the efficiency of ports. Some PIXEL models (developed in T4.1, T4.2, T4.3 and T4.4) also have a clear interaction with predictive algorithms (T4.5).</p>
<b>Exploitable results</b>	<p>This deliverable contributes to develop interoperability of environmental related models by identifying the inputs and outputs of each model and describing a methodology considering impacts of energy and transport on environmental pollution. This deliverable contributes to develop a methodology to model port activities and their impact on the environment by allowing the quantifications of emissions. The port activities scenario (combined with energy model and emission factors) that is proposed in this deliverable is transferable and applicable for other small and medium European ports. This deliverable also contributes to a better identification of predictive algorithms that could be used to improve port efficiency by mitigating environmental impacts.</p>
<b>Work plan</b>	<p>This deliverable is the result of the work performed from M4 to M18 in task T4.1, T4.2, T4.3 and T4.4. This document also has a close link with WP3: use-cases description (T3.3) and requirements specification (T3.4); with WP5: methodology (T5.1) and KPI definition (T5.2); with WP6: models will be integrated in PIXEL Operational Tools (T6.4) and with WP7 as models will be integrated, tested and validated in real conditions. Content of this deliverable describes the methodology used for</p>

	development, implementation and tests of the PIXEL models and will be used as a basis for Operational Tools in WP6.
<b>Milestones</b>	This deliverable contributes to reach the milestone MS4 by providing a description of the overall methodology of the PIXEL Models.
<b>Deliverables</b>	This deliverable uses inputs from the deliverable D3.4 and D4.1 in order to express modelling needs of ports. This deliverable has a close interaction with the deliverable D3.2 regarding the definition of a set of minimum requirements regarding modelling and data analysis. It also gives inputs to D4.4 by contributing to identify possible candidates and usage of predictive algorithms. It impacts other project activities relating with models and data analysis (integration WP6 and real test WP7).
<b>Risks</b>	By working with the WP3 (T3.3) and with an analysis of every port-operation process to be modelled this deliverable reduces the risk that some processes cannot be modelled as they depend on too many factors or they are overmuch random. The deliverable includes in appendices a technical description of the different use-cases regarding modelling and data analysis and provides information about available data and modelling scope.

## 1.2. The rationale behind the structure

This report describes the work performed in T4.1, T4.2, T4.3 and T4.4 of the PIXEL project and how PIXEL models will be integrated in the PIXEL Operational Tools. Except for the introduction and the conclusion, each section describes a specific task related to PIXEL models. This deliverable is organised as follows:

1. **Introduction to PIXEL Models:** This section focuses on the global vision of PIXEL models, the objectives and scopes of the models in the framework of PIXEL. This section also aims to provide common definitions and notations in order to present PIXEL models *in a standardized notation to define precisely the methodology*.

The next sections share the same structure and are focused on describing a specific model each:

- Introduction: Objective and scope of the specific model and a data source description.
- Description of the overall methodology.
- Description of how the model works with sample or real data if they are available.
- Requirements for the integration in the PIXEL Operational tools.

These sections are:

2. **Environmental management model of port:** This section reports the work done in T4.1 in order to *develop a model of environmental management of port*. While describing how to build a port activity scenario, this section focused on *developing interoperability* of models and has close interaction with all the other tasks in WP4 and especially T4.2., T4.4
3. **Energy demand model:** This section reports the work done in T4.2 to model *the port's energy demand to provide information about energy availability, reliability and efficiency*. This section develops model *to know the present and future power demand of port operations*.
4. **Hinterland multimodal transport model:** This section reports the work done in T4.3 to model the evacuation of goods *to hinterland and a modelling of the mode of organization of the port passage*.
5. **Environmental pollution models:** This section reports the work done in T4.4 to model the air and noise pollution inside ports. This section works with *a localization of global and local sources of emissions* in order to provide a heatmap of noise and air pollutants dispersion. Results will be presented *as long-term trend and integrate a wide range of data collected in the PIXEL framework*.

This document comes with four appendixes that provides inputs about the data models for port activities, links between WP4 and other PIXEL work package, state of the art in PIXEL context and paper published based on the work done in WP4.

- **Appendix A** provides a description of data models for the port activity scenario.
- **Appendix B** presents how the WP4 is interconnected with the other technical WP of PIXEL
  - **B.1** gives a technical description of the four use-cases with a special focus on modelling and data analysis. It describes modelling needs, available data, scope and boundaries of port activities modelling.
  - **B.2** explains how port activities modelling and PIXEL models are useful in order to evaluate, estimate or predict environmental impacts. It makes a link between the Port Environmental index and PIXEL models (WP5).
  - **B.3** gives inputs about the Operational tools and how the PIXEL models will be integrated in the PIXEL architecture (WP6).
  - **B.4** give inputs on how PIXEL Models will be tested by the end-users during the integration phase (WP7).
- **Appendix C** provides a literature and state of the art review for each of the PIXEL models.
  - **C.1** Environmental management models of port
  - **C.2:** Energy models
  - **C.3:** Hinterland multimodal transport models
  - **C.4:** Environmental pollution models
- **Appendix D** reproduced abstracts of articles written with work done in WP4
  - **D1:** Noise Pollution – Introduction to the state of the research and the implementation in the Horizon 2020 Project PIXEL, Stjepan Piličić, Luka Traven, Teodora Milošević, Igor Kegalj, Ante Skoblar, Roberto Žigulić, 8<sup>th</sup> International Conference on Maritime Technology, Rijeka, November 2019.
  - **D2:** Air Pollution Dispersion Modelling in Ports Areas, Teodora Milošević, Lado Kranjčević, Stjepan Piličić, Marko Čavrak, Igor Kegalj, Luka Traven, 8<sup>th</sup> International Conference on Maritime Technology, Rijeka, November 2019.
  - **D3:** Small and Medium Ports’ Activities Modelling: Introduction to the PIXEL approach, Erwan Simon, Charles Garnier, Ignacio Lacalle, Joao Pita Costa, Carlos E. Palau, MTC Conference, September 2019, Rome.

### 1.3. Version-specific notes

This document is the second version of the deliverable “PIXEL models”. This deliverable provides a full updated of the deliverable D4.1 by synthesizing all the work done between M9 and M18 by task T4.1, T4.2, T4.3 and T4.4. It gives a **full technical description of port-operation to model and provides elements related with model accuracy, scope and how to have a concrete implementation and integration of the models.**

Comparing with the previous version of this deliverable, the present version main changes are:

- New document structure: the core document is now fully dedicated to the PIXEL models and the sections related with “Links with other WP” and “State of the art” have been moved to appendices.
- The “Introduction to PIXEL models” has been updated by:
  - Adding a summary of the different PIXEL models components;
  - Relating PIXEL models with PIXEL’s objectives and requirements;
  - Adding to the “Common definitions and notations” section a clear and technical description of what we considered as the Port Activities Scenario (PAS);
  - Adapting the whole section with the work done between M9 and M18.
- Each section that describes a PIXEL model now included:

- A description of the *overall methodology* which allow readers to understand what the theoretical framework is behind each PIXEL model, how to use this model in the reality of port activities and how it will be useful for the Port of the Future.
- A description of requirements in order to integrate PIXEL models in the PIXEL operational tools:
  - Data requirements;
  - Visualization and UI, Triggers and KPIs;
  - Training requirements;
  - Transferability requirements.

## 2. Introduction to PIXEL models

### 2.1. Vision

This section introduces the overall vision and roadmap of the PIXEL's models, through the presentation of some key concepts. This roadmap has been followed by all WP4's consortium partners during development/use of PIXEL models.

#### *What is the starting point?*

Ports are essential nodes in the multi-modal supply chain. Several stakeholders interoperate within the same port area assuming different roles with various constraints and requirements. Therefore, ports are complex ecosystems with a multitude of actors (port authority, terminal operators, carriers, citizens, legislators) producing and consuming each day huge quantities of information. Operational data in ports are continuously increasing and depend on different stakeholders. Among these data sources we can mention the following ones: resources tracking, container status, vessel operations, crane scheduling, surface or berths available, air/water quality measurements, or energy consumption and production. In most cases, an optimal exploitation of all the knowledge is still to be unleashed. This is due to three main circumstances:

- (i) the information exchange still remains managed in a document-centric fashion, both for reporting to regulatory bodies and to perform the day-to-day service,
- (ii) if digital information applications exist, they are isolated and oriented just for very specific purposes,
- (iii) personnel at the ports do not have enough knowledge and awareness of the benefits of digitalisation of processes.

Agents within a port are focused on specific tasks (such as global and financial management of the port, load and unload of cargo or berthing) occupying the whole spectrum of ports functioning. They are equipped with high level skills on business management and day-to-day operations but, as per normal case, they are seldom driven by data-valuation procedures. Therefore, traditional mindset in ports about information exchange and data exploitation has been focused on just regulation compliance rather than on real value extraction supported by modern technologies (Celtinkaya, 2011).

Today, European small and medium-sized ports (in the light of discussions with PIXEL's ports and other actions such as DocksTheFuture sessions 3<sup>rd</sup>-7<sup>th</sup> December 2018) are scarcely equipped with tools to calculate, estimate or predict impacts on energy consumption, transport networks and environmental pollution of port activities. These tools are lacking at the ports in order to put in place decision-making solutions to quantify (even roughly) the environmental impacts of their activities. To provide these tools we argue that two actions are needed:

- i) Development and implementation of tools to model the impacts (in terms of energy, transport and pollution) of port activities.
- ii) Qualified data coming from sensors, port data, etc. to calibrate, parameterize, feed or develop the models.

PIXEL aims at developing both actions. In this deliverable we present how ports activities can be modelled and how their environmental impacts can be estimated or predicted. We also have a focus on the available data in ports since model quality is largely depending on data quality. These models will be tested and validated in WP7 during the integration phase. Looking at previous initiatives undertaken in port operations modelling and simulation (Dragovic, 2016), PIXEL clearly contributes and extends previous research, by:

- Focusing on modelling small and medium-sized European port operations, considering both the available data and the required degrees of modelling precision
- Placing emphasis on the environmental impacts of port operations, covering:
  - (i) Port-direct – Scope 1;
  - (ii) Port-indirect – Scope 2;
  - (iii) Port tenants’ indirect – Scope 3 environmental impacts (IMO, 2018).
- Boosting the benefits of port IoT infrastructure to enhance the efficiency of the modelling approach.

***What do we want to achieve? A modular and adaptable approach for modelling port activities***

PIXEL’s models aim at defining and implementing port’s activities models to be used in order to manage the port in an efficient way and adapted to the environmental needs, including energy demand and production, hinterland multimodal transport, atmospheric and noise pollution. In order to achieve these ambitious objectives, the steps listed below have been followed to address the specific objectives of the WP4.

*Table 2: WP4 steps for PIXEL models development*

Steps/Objectives	How has it been addressed in WP4?
<i>Elaborate a clear and precise technical description of the port-operation to model (activities catalogue, optimization parameters, scope definition).</i>	In the beginning of WP4 a huge work in collaboration with WP3 and ports have been done to clearly express modelling and data analysis needs and requirements. This has been used as a basis for model development. Readers will find more information in Appendix B.
<i>Establish a list of data available in ports in relation with the port-operation to model. These data will be qualified in terms of accuracy, frequency, representativeness, etc.</i>	This work has been done by each task leaders of WP4 in collaboration with ports. Readers should note that PIXEL models are not just theoretical model but that they have been established based on the reality of available data.
<i>Choose, develop and implement the best approaches depending on the available data (selection of an adequate level of details). In WP4 we had focused on gathering a data sample that is enough representative to build a model upon it. The full data acquisition process is done under WP6 and WP7.</i>	Benefiting from the four ports participating in the project, PIXEL models have embedded the operational reality and the data of actual port operations. This led to the development of models adapted to small and medium-sized ports, both on the available data (using port but also open data) and on the expected degrees of precision.
<i>Defining links between the different models.</i>	This has been addressed both in a global way at WP4 coordination level and by each task leaders to ensure that a result of one model could be used as an input for another one. Results of the port activity scenario are used by the energy model in order to provide prediction of energy consumption. Then energy results can be translated into emissions rates and used as inputs for air pollutants dispersion model.
<i>Define a methodology to evaluate environmental impacts based on energy demand and production models, hinterland multimodal transport models and atmospheric and noise pollution.</i>	The port activity scenario defined by the work done in T4.1 allows to model port supply chains. This first step is used as an input for evaluating the energy consumption and with the used of emissions factors to provide an estimation of pollutants emissions. By providing a full methodology to quantify emissions we offer ports a way to evaluate their environmental impacts. Moreover, the environmental models (air and noise) provide tools to better understand how emissions affect the port-city neighbourhood.



The overview of PIXEL’s models can be summarized using the Figure 1. The PIXEL platform is built upon a data-driven perspective and delivering an IoT architecture that provides a robust technological bundle for modelling activities. PIXEL platform involves, in a schematic view, four stacks (beside security). As seen in Figure 1, the four stacks are acquisition, management, modelling and diffusion. These stacks are organized in such a way that each of them is part of a tree with data like sap flowing between them. The following sections aims to present the modelling layer in a detailed but a comprehensive way (represented in green in Figure 1).

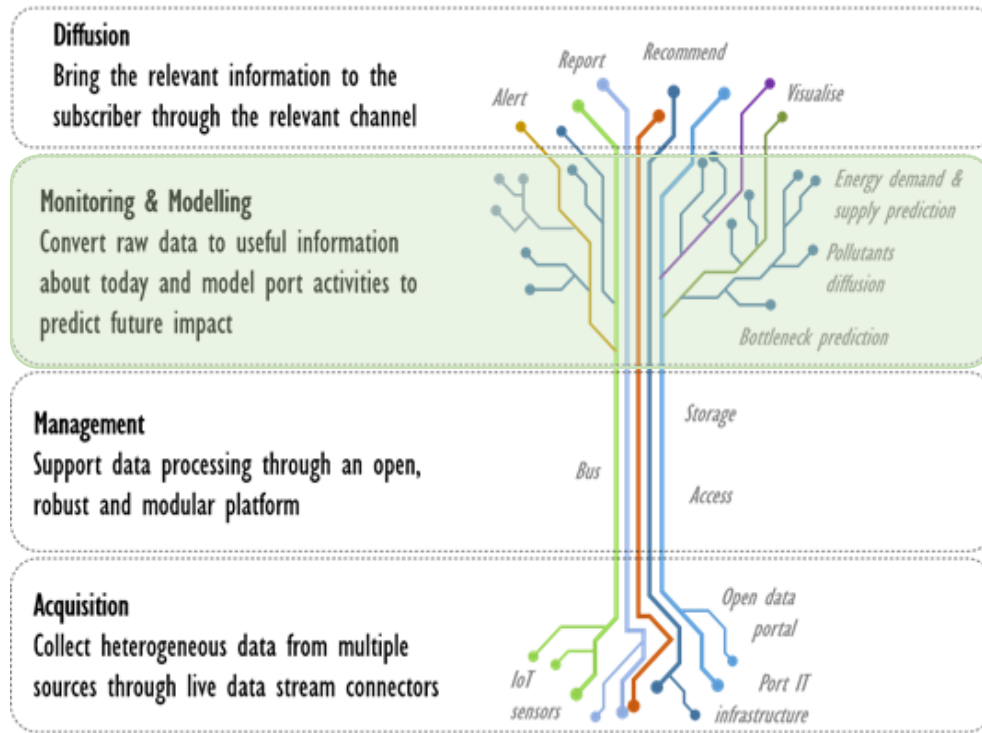


Figure 1: PIXEL’s models vision (WP4 focused on the green part)

In PIXEL WP4 we have also identified some points of convergence both with the Port Emission Toolkit (GloMEEP and IAPH, 2018) and the Global Logistics Emissions Council Framework for Logistics Emissions (GLEC Framework) (Smart Freight Centre, 2019). We share some common ideas:

- GloMEEP has already worked on how to plan a port emissions assessment and has proposed a methodology for selecting pollutants, emissions sources, geographical and operational domains, temporal period and frequency of the inventory. This methodology could be adapted for small and medium ports and PIXEL can contribute with a methodology to move from an emissions inventory to an environmental assessment of ports through a single, intelligent and adaptable indicator that will be the PEI. This last part is mainly addressed in WP5.
- They have also defined some key elements as activity data. This has been already discussed by the PIXEL consortium. This approach can be used to have average data related with port activities.
- In the Port Emission Toolkit, they focus on port emissions and give a full methodology to have a comprehensive emission inventory (emission factors, activity data) not only for seagoing vessels but also for cargo handling equipment, on-road heavy-duty vehicle, rail locomotives, and electrical grid emissions. They also give some metrics for equipment, activity and emissions. This metrics can be used as a basis for PIXEL models inputs.
- GLEC Framework proposes to use modelled data in order to estimate emissions and reminds that “*the relevance of the model’s output will depend on the level of detail that is available about the transport operation and the assumptions made, as well as the model’s algorithms*”. Moreover, they argue that “*modelled data are much more likely to be representative of actual conditions than default data*”. Our aims by developing PIXEL models are fully aligned with this description: to provide tools for small and medium ports in order to have a better understanding of their activities (rather than default values) and their impact on the environment.

## 2.2. Integration of PIXEL models in the PIXEL architecture

WP4 goal is to provide several Modelling Tools to the PIXEL Framework. Indeed, WP4 proposes models, data analysis and algorithms in order to manage port in a more efficient way and adapted to the environmental needs. To do this WP4 considers the environmental impacts identified in WP5 as necessary to the Port Environmental Index and tries to provide raw metrics through an emissions quantification. Then in WP6 (especially in T6.4 PIXEL Operational Tools) those models, data analysis and predictive algorithms are integrated through the Operational Tools. Thus, WP4 proposes a clear and validated (meta)model adapted to the needs of ports defined in WP3. Together these modelling (WP4) and operational (WP6) tools constitute a decision support tool providing a useful and transversal knowledge for cargo operational management. It will allow operators to evaluate the environmental impact of activities scenario, and to compare them for an optimal choice regarding environment as the primary metric. Our purpose is to develop the different components as shown in Figure 2.

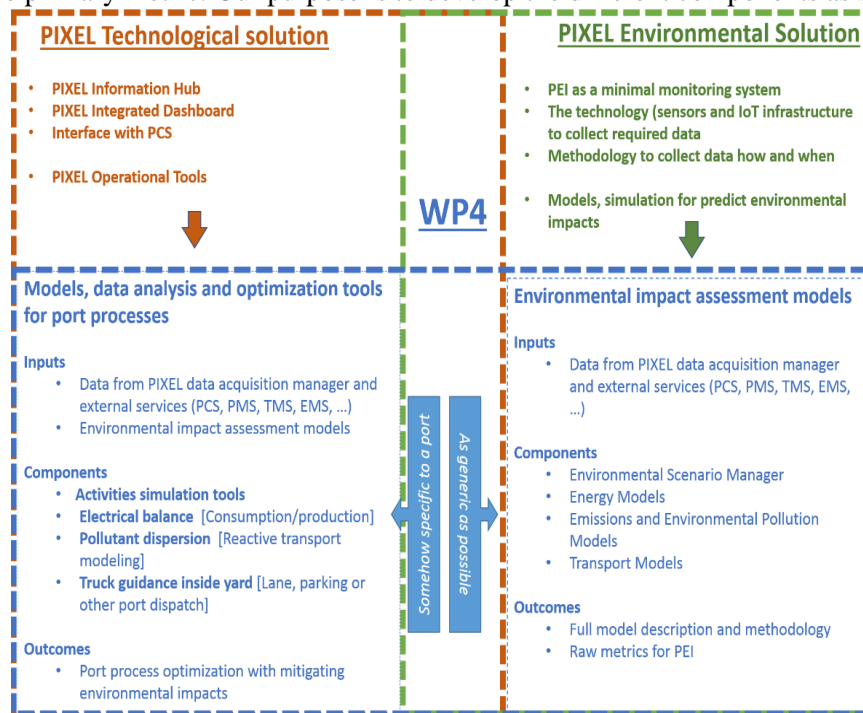


Figure 2: PIXEL Models components

## 2.3. Scope

Small and medium-sized ports' organizational systems vary widely. They express different needs of modelling activities:

- i. Live monitoring;
- ii. Past activities assessment;
- iii. Short- and long-term forecast;
- iv. What-if scenario.

Another important issue for modelling port activities in an efficient way lies on the ability to deal with various degrees of data completion, precision and accuracy. Indeed, even if PIXEL platform provides a tool to collect data from a large scope of sensors, some information could be missing or incomplete. This is due to the variety of agents composing the supply chain and methodologies besides the integration degree of operational and field information in real time. Because data is a key point in order to have useful models and because data collection is an intensive phase, PIXEL model of port activities can be used with different levels of details regarding input data. Depending of the purpose of modelling and the expected precision, inputs data could be less or more detailed. Thus, ports can use PIXEL models with comprehensive data (detailed model and low uncertainty), screening data (some local input and external data leading to a significant uncertainty) and scaled data (average and non-specific input data leading to great uncertainty and just giving an order of magnitude).

PIXEL models will consider cargoes as the functional unit. Therefore, we study cargoes transitions between areas (from sea to hinterland) through transition operations (i.e. unload, load and transport) by machines (e.g. crane, truck etc.). A specific composition of cargo's transition operations (involving different machines and operators) will be referred to as a supply chain, as illustrated in Figure 3. The modelling of supply chains applying to different types of cargoes will enable us to correctly identify the energy sources involved, the types of equipment used, the sources of pollution and the frequency with which these cargoes enter and leave the port. Each model has its own assumptions and boundaries, but transitions of freighters outside the port ecosystem (for example at sea or in the destination lands of the cargoes) will not be integrated into the PIXEL models.

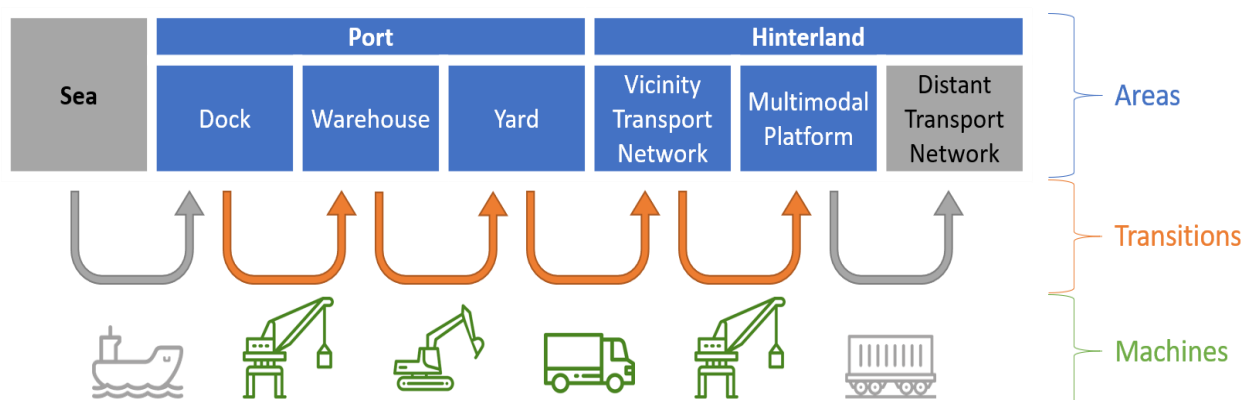


Figure 3: WP4's scope illustration through a cargo's supply chain example. Grey elements are outside scope.

## 2.4. PIXEL Models components

### Port and City Environmental Management Model

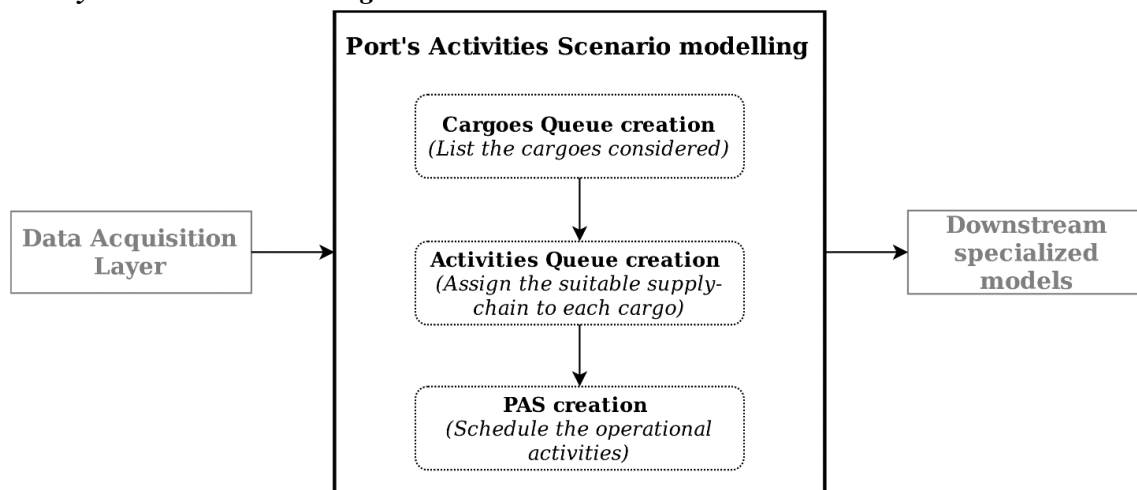


Figure 4: Schematic view of the Port Activities Scenario (PAS)

As port activity is generated by incoming and outgoing cargoes in the port ecosystem, PIXEL models consider cargoes as the functional unit. Input data from this modelling are mainly based on:

- i) vessel planning (arrival date, cargo type and tonnage,
- ii) activity data (details related to the transition of a cargo),
- iii) operational data (refer to the technical specifications of engines and equipment used)
- iv) emission source data (related to emissions factors of engine and equipment).

The knowledge and modelling of the supply chain and port's activities (type of machine, duration of use, position in the port) enable us to build activity scenarios that are used to identify the energy sources, local emissions of pollutants but also to estimate the flow of cargoes entering or leaving the port. Using this approach, the modelling scenario will be used by the ports as a support for decision making.

### Energy demand prediction

For operational actors in ports, energy efficiency is an important issue, both from the environmental and economic perspectives. In order to optimize the energy flows inside the port, a prerequisite is to manage and quantify energy consumption and production in the context of complex industrial processes. PIXEL enables such quantification for small and medium ports by focusing on the three complementary elements:

- i) energy consumption (fossils and electric) associated to cargo transition across the port,
- ii) energy produced by local sources such as photovoltaic panels,
- iii) balance between energy consumption and production.

Figure 5 shows PIXEL’s approach to predict energy consumption related to port activities. This approach enables a predictive estimation if the port activities scenario is known (e.g. maximum net energy consumption during next week).

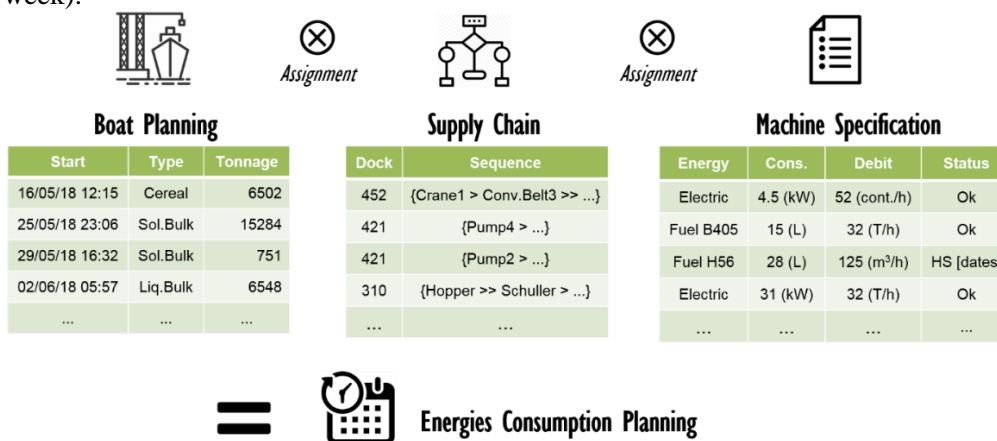


Figure 5: Illustration of energy consumption models in PIXEL

### Hinterland multimodal transport model

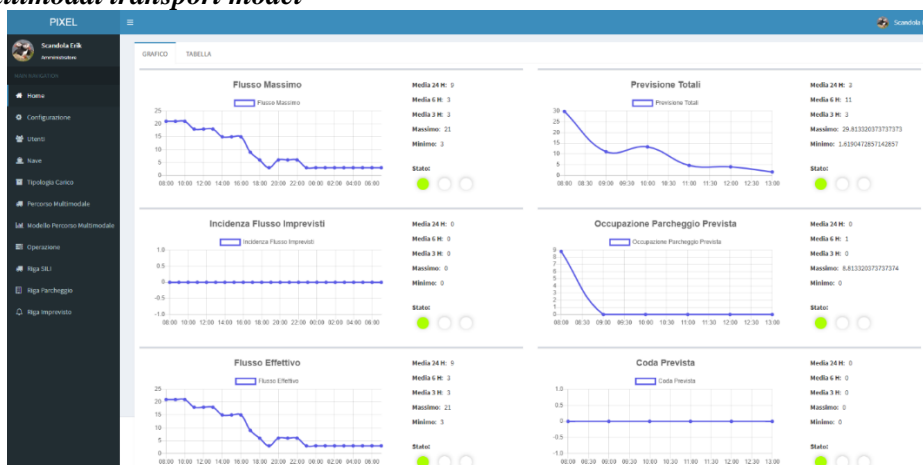


Figure 6: Example results of the transport model

The model will help to understand if a different traffic management has a positive impact on congestions issues, citizens risk on the road and environmental impacts. The main result that will be reached is an effective decision support tool to optimize the re-routing of trucks from the Port towards SDAG or other infrastructures, and so facilitate the staff working in both entities (between ASPM and SDAG). The model has been split in two sub models, one related to intermodality way of transport (applied on slabs traffic between ASPM and Aussa Corno industrial district), the other one related to traffic and parking inside port premises and the possible rerouting to SDAG. We are going to call the first one “intermodality sub model” and the second one “traffic sub model”.

### Environmental dispersion models

Cargo handling within ports, and to/from the hinterland loading and unloading cargo undeniably involves emissions of pollutants. For example, loading or unloading a cargo of dry bulk can cause a significant amount

of dust in the atmosphere and generate a lot of noise. Thus, the sources of emissions generated by the supply chain of cargo are not negligible and have direct effects on the port environment. Based on existing measurements and port activity data, the air and noise model should simulate the air and noise pollutant dispersion caused by various activities and operations taking place within the port. By using historical data, it will simulate the current state of the ambient air/noise in the port and with help of weather predictions models, it should be able to simulate the possible future air/noise quality situation. These simulations can assist the port manager/operator in the decision-making process in order to optimize various activities within the port and minimize their impact on the environment.



Figure 7: Example of air and noise heating maps.

## 2.5. Relation with PIXEL objectives and use cases

All the work described in this document as part of tasks T4.1, T4.2, T4.3 and T4.4 aims at the fulfilment of PIXEL' objective n°4: **“Model and simulate port-operations processes for automated optimisation”**.

Firstly, the development of a port activities scenario by modelling supply chains for different cargoes will be useful for small and medium port for a better understanding of their different processes. This port activities scenario will be served as a first basis for other modelling activities and provide useful *links between the different models and guarantee interoperability* between them. Secondly, it will be used as a basis in order to make an inventory of emissions due to port activities. This will be useful in order to optimise port-operations processes *to evaluate environmental impacts*. Thirdly, it will be used to establish time series of energy consumption due to port activities and in a second time optimise their energy needs. Fourthly, vessels' calls, which are included in the port activities scenario will be used to predict the traffic inside the port that could lead to an *optimisation* of the traffic paths. Finally, it will help to identify local and global sources of air pollutants and noise emissions that will be used to create dispersion maps allowing ports to know how they are impacting their neighbourhood.

These modelling needs have been directly expressed in D3.4 (Use cases and scenarios) by the four use cases in PIXEL. Readers must keep in mind that PIXEL models are developed considering the port reality and accessibility to data in order to develop models that will be really used and not just some kind of theoretical framework. More info about the modelling needs of ports are available in Appendix B1.

### 2.5.1. Use case of GPMB

GPMB use case is mostly connected to energy management. One of the challenges of GPMB is to become a greener and more cost-attractive port. In order to reach this, the first step is to be able to know with a good accuracy how many energies is consumed by port activities.

As expressed in D3.4 *“It is planned that simulation will be able to predict, at least energy consumption related to ships operations and involved logistics chain.”*. To do this the energy model is developed for *estimating the real-time quantity of energy consumed during port operation depending on the type of cargos and vessels*. The port activities scenario was also developed in order to be able to have a clear list of all the port activities that are taking place over a certain period. Many works have been done to develop a tool to facilitate the matching of goods, supply chains and machine specification. This is a must to have for predicting energy consumption.

### 2.5.2. Use case of Port of Monfalcone

Port of Monfalcone use case relates to our traffic use case. The main challenge of Port of Monfalcone is to better understand how the port's freight traffic impacts urban and port's surrounding area.

As expressed in D3.4, Port of Monfalcone aims at reducing “*congestions in port areas, reduced use of inland premises*” and “*use of rail and inland-ports services*”. The transport models in PIXEL addressed these issues by i) modelling the traffic inside the port premises due to the vessels arrivals and departures and modelling the congestion inside the port and ii) setting up a model for the evacuation of slab by road and by train in the hinterland.

### 2.5.3. Use case of Port of Piraeus

The port of Piraeus is very near the city of Athens and residential area. When a lot of traffic is experienced in passengers' terminals it generates noise and air pollution. In order to better understand and predict the port contribution to noise and air pollution, the model develop in PIXEL aims at providing useful tools to port agents to evaluate them.

As expressed in D4.3, Port of Piraeus aims to model air pollution in order to “*estimate the influence of the air emissions related with the port activities (cruise and passenger terminals) at the city and have predictions for the effect at the city (emissions alarm mapping) by the air emissions associated with the cruise and passenger Terminal*”. The air dispersion model develop in PIXEL provides results with accuracy depending on i) space: pollution across a geographical area ii) time: pollution throughout one day on a per hour basis. Port of Piraeus aims also to model noise pollution in order to “*run simulations and co-evaluate the output with the results of the LAeq indicator measurements in order to have adequate data for noise mapping and establish an accurate estimation of the noise level impact of the Container Terminal in the residential nearby area*”.

### 2.5.4. Use case of Port of Thessaloniki

The use case of the Port of Thessaloniki focuses on the interoperability of city and port in freight traffic and in pollution impact towards the city.

As expressed in D4.3, Port of Thessaloniki aims to model air pollution in order to “*estimate the air pollution impact related with bulk and handling cargo activities. The predictive model may accept input parameters for letting environmental operators alter a factor (e.g. weather conditions for next day), and then provide a picture of the amount and area that will get affected by port operations. Some sort of visualization by dispersion maps is envisioned. The developed model should try to generate any potential assumptions (e.g. pollution deriving from ships, machinery and trucks) and combine them.*”

Port of Thessaloniki aims also to model noise pollution to *estimate the noise pollution impact related with handling cargo activities.*” Knowing modelling results “*some triggering action will relate internal (e.g. re-schedule operation) to the port, but this information can be shared with the municipality to generate an integral environmental plan.*”

## 2.6. Relation to requirements

The relations between PIXEL Models and PIXEL Requirements have been deeply investigated and described in detail in “D3.2 – PIXEL Requirements Analysis”. More specifically for each partner, both requirements related with Predictive Algorithms (PA) and Model Optimization (MO) have been collected and analysed. A relevant aspect of the PIXEL project, concerning modelling and forecasting, is represented by requirements covering both MO and PA. Such products, in fact, deal with modelling and forecasting activities, by providing ports with a set of tools aimed at proficiently cope with respective use cases. In particular PA and MO will be proficiently exploited in order to perform:

- Transport Modelling;
- Pollution Modelling;
- Energy Modelling;
- Traffic Forecasting.

Table 3 provides a full list of requirements directly or indirectly related to the implementation of PIXEL Models.

*Table 3: Relation to PIXEL requirements*

Requirements	Addressed in sections
<b>Common functional requirements</b>	
Import historical data [36] Interaction with models [41] Anomaly and event list [44] Anomaly and event detection [45] Catalogue of models [62] Detection of anomalies [63] Port Operational KPI list [70]	These requirements are initially addressed in all tasks T4.1, T4.2, T4.3 and T4.4. However, all these points are not directly addressed in WP4 but will follow conventions defined in WP6 in order to allow fulfilment of those requirements in WP6.
<b>Port of Bordeaux – Energy Management Use Case</b>	
Modelling and analysis of energy consumption during ship handling procedures [15] Optimization of photovoltaic energy production and consumption [19]	Section 4
<b>Port of Monfalcone – SDAG – Intermodal Transport Use Case</b>	
Port congestion forecasting [34] Port congestion simulation [35] Port - SDAG highway congestion forecasting [37]	Section 5
<b>Port of Thessaloniki – Port City Integration Use Case</b>	
Estimate air pollution impact of handling cargo [56] Estimate noise pollution impact of handling cargo [57] Estimate air pollution impact of bulk cargo operations [58]	Section 6
<b>Port of Piraeus – Port City Integration Use Case</b>	
Estimate air pollution impact of cruise and passengers' ships related activities [78] Estimate noise pollution impact of cargo ships related activities [90]	Section 6

## 2.7. Common definition and notation for PIXEL models

The following sections aim at presenting the PIXEL models *in a standardized notation to define precisely the methodology*. First, we define what is a port activity and the data needed to model it. Then we define what is considered as a scenario for PIXEL models and what are the different types of data that PIXEL models can use as inputs. Finally, we introduce the port activity scenario.

## 2.7.1. Port activity

The knowledge of the supply chain (type and number of machines, duration of use, position in the port), allow us to know the energy sources used, local emissions of pollutants but also to estimate the flow of cargoes entering or leaving the port and the resulting traffic. In this section when we speak about port activity, we refer to the port operations involving:

- loading and unloading of cargo to and from ships;
- transfer of cargo inside the port (docks, storage areas, gates);
- supportive operations (warehouses and docks lighting, reefer areas energy supply, etc.).

### 2.7.1.1. Activity's data structure

PIXEL models' input data are relative to cargoes handling from one area to another through machines. So, initially, we distinguish between four data types:

- Activity
- Cargo
- Area
- Machine (equipment)

The relation between the data types is the following:

*An activity is the use of one machine in order to handle one cargo unit between two areas.*

A succession of activities will be called a scenario. This could be seen as a Gantt chart. The Figure 9 shows an example of what the activity data structure looks like.



Figure 8: Activity's data structure consists in handled cargo's data projected on time and machine/space axes

The operations along with their explanatory notes for the **Breadbulk** cargo of Figure 8 are described in the below table:



Table 4: Example of an activity scenario

Operation	Notes
<b>Machine 1</b> handles the cargo at the <b>Dock</b> area from 01:00 AM to 03:00 AM.	A crane is used to unload breadbulk from the ship to the dock area from 01:00 AM to 03:00 AM.
<b>Machine 3</b> handles the cargo at the <b>Warehouse</b> area from 03:00 AM to 07:00 AM, but <b>not all data is available for this activity</b> .	A loader is used to carry breadbulk from the dock area to the warehouse and stack it there from 03:00 AM to 07:00 AM, but the distance between the dock and the warehouse is not known.
<b>Machine 5</b> handles the cargo at the <b>Yard</b> area from 07:00 AM to 09:00 AM.	A loader is used to load trucks (using lane 2 of transport network, i.e. road network) at the yard area from 07:00 AM to 09:00 AM.
The cargo is handled at the <b>Land Gate</b> area from 09:00 AM to 10:00 AM.	The trucks pass the land gate between 09:00 AM and 10:00 AM.
The cargo is using <b>Lane 2</b> of the Transport network from 09:00 AM to 10:00 AM.	The trucks carry the cargo from 09:00 AM to 10:00 AM.
<b>Machine 6</b> handles the cargo at the <b>Multimodal Platform</b> area from 10:00 AM to 11:00 AM	All the trucks have arrived at the Multimodal Platform area at 10:00 AM. A crane is used to transfer breadbulk from the trucks to a railway wagon from 10:00 AM to 11:00 AM. Train is considered to be using Lane 3 of the Transport network, i.e. railway network
The cargo is using <b>Lane 3</b> of the Transport network from 12:00 PM to 02:00 PM.	

The port operations will be constituted from different activities as shown in Figure 8. In order to perform a modelling of the port operations, scenarios and activities, we need to know the data types describe in the following sections.

### 2.7.1.2. Activity data

These data refer to the details related to a transition of a cargo: duration of the operation, type of machine used, distance travelled, etc. These data thus mainly refer to the logistics chain linked to a cargo.

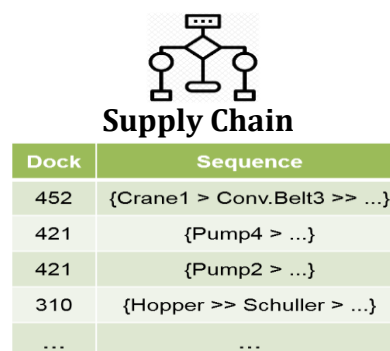


Figure 9: Example of a simple supply chain modelling

In the above table, the activity sequence is represented by placing the equipment in the order they will be used.

### 2.7.1.3. Operational data / Machine specification

These data refer to the technical specifications of the machinery and equipment used. These data will specify the type of energy used, the consumption according to the mode of operation, the status of the machine, its operating limitations, etc.



#### Machine Specification

Energy	Cons.	Debit	Status
Electric	4.5 (kW)	52 (cont./h)	Ok
Fuel B405	15 (L)	32 (T/h)	Ok
Fuel H56	28 (L)	125 (m³/h)	HS [dates]
Electric	31 (kW)	32 (T/h)	Ok
...	...	...	...

Figure 10: Example of a simple machine specification

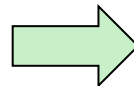
### 2.7.1.4. Emission source data / Emissions factors

These data detail for each machine, engines or other sources used in the transition of a cargo, the sources of emissions linked to it. These data are very often obtained and based on emission factors allowing to translate the consumption of energy into quantity of pollutants emitted.



#### Machine Specification

Energy	Cons.	Debit	Status
Electric	4.5 (kW)	52 (cont./h)	Ok
Fuel B405	15 (L)	32 (T/h)	Ok
Fuel H56	28 (L)	125 (m³/h)	HS [dates]
Electric	31 (kW)	32 (T/h)	Ok
...	...	...	...



#### Emission unit

Noise (dB)	CO <sub>2</sub> (g/h)	PM <sub>10</sub>	...
75	235	75	...
81	203	81	...
78	178	78	...
87	368	87	...
...	...	...	...

Figure 11: Example of how to obtain machine emissions

### 2.7.1.5. Vessel planning

These data refer to the vessels arriving at the ports with the description of the type of cargo, the tonnage, their expected date of arrival and departure. These data thus make it possible to know the expected flow rate for each type of cargo.



#### Boat Planning

Start	Type	Tonnage
16/05/18 12:15	Cereal	6502
25/05/18 23:06	Sol.Bulk	15284
29/05/18 16:32	Sol.Bulk	751
02/06/18 05:57	Liq.Bulk	6548
...	...	...

Figure 12: Example of boat planning

Although these data alone are not enough to implement all PIXEL models, they will be necessary and common to all and could be considered as a requirement for PIXEL models. Such information can be extracted for example from:

- FAL forms,
- PCS,
- Literature review,
- Analysis of port activities, etc,
- Sensors,
- External web services,
- Imputation by hand.

### 2.7.2. Scenario

For each cargo, there are several ways to arrange transition operations between areas. A hypothetical combination of those transition operations (for one or more cargo) will be denoted as a scenario. This scenario will be designed by port operators and the end-users of modelling and data analysis tools. To do this, an interface to fulfil the different parameters of a scenario will be developed in WP6. In PIXEL we do not have terminal operators to provide useful information about cargo operations and therefore we will rely on port operations. WP4 aims at providing the ability to get environmental impact metrics for a scenario, and to compare it with alternative scenarios. Thus, PIXEL modelling tools can be used to order or evaluate scenarios according to an optimization metrics.

That is why the main and central component of the PIXEL modelling approach is the Port's Activities Scenario (denoted thereafter as PAS) modelling. Its purpose is to establish an operational description of the port activities related to cargo handling. The produced PAS is a data-model listing all the considered activities' time series. It allows the use of specialized models based on the PAS as an input, for energy consumption, emissions quantifications and other externalities quantification.

The main input for PAS modelling is the *cargo* arrival planning, completed with parameters relatives to the sequence of *operations* required (thereafter call *supply-chain*) and the corresponding *machines* technical specifications. In order to build a PAS, three steps are followed:

1. Cargoes inventory,
2. Supply-chain mapping,
3. Operation schedule calculation.

Those three steps and the corresponding data-model are presented in detail thereafter.

### 2.7.3. Type of data source

Data is a key point in order to have useful models and data analysis and data collection is an intensive phase. Models and data analysis can be developed using different levels of details regarding data. Indeed, depending of the purpose of modelling and the expected precision, inputs data could be less or more detailed. As defined in GloMEEP and IAPH, 2018 and Smart Freight Centre, 2019 we also consider the following types of data.

#### 2.7.3.1. Scaled data

These data use approximations to obtain an order of magnitude corresponding to the types of activities considered. These data are obtained by integrating external data produced by a port having a similar activity and representative of the real activity that is to be modelled. The use of this type of data assumes that port activities are similar and should be adapted, for example, to port traffic. The results obtained using this type of

data will also be approximate. Therefore, the results of the models based on this type of data have the following features:

- Average and non-specific input data for model port activity.
- Results based on an adaptation according to scale parameter (for example maritime traffic).
- Results with great uncertainty.

This type of data is useful when no information is available and when we are just interested by having an order of magnitude.

### 2.7.3.2. Screening data

These data are more detailed than scaled data and use data more specific to the port activity considered. These data use local sources for example on the description of the supply chain but use external data for emission factors. The results of the models based on this type of data have the following features:

- Some local input data and external data for model port activity.
- Results based on a simplification of some inputs (for example average energy consumption of cranes and trucks).
- Results with significant uncertainty.

### 2.7.3.3. Comprehensive data

These data are based on the detailed description of the port activity to be modelled with a complete knowledge of the supply chain, machine specifications, emission factors, etc. These data can come from sensors, administrative documents or expert knowledge. These data will yield much less uncertain results but require a lengthy data collection. The results of the models based on this type of data have the following features:

- A detailed modelled of the port activity.
- Results can be verified and validated using some measurement.
- Results with low uncertainty.

## 3. Environmental management model of port

Port activities modelling is the first step in order to evaluate the environmental impact of the port's operations based on energy demand and production models, hinterland multimodal transport models and air and noise pollution models. This section defines a methodology for the modelling of these activities that is adapted to small and medium European ports.

### 3.1. Introduction

An environmental management model aims to model the environmental management of an organization by allowing the calculation of the environmental impacts of its operations. In PIXEL, the types of models that are developed and will be related with ports' operations are:

1. Energy demand and production models.
2. Hinterland multimodal transport models.
3. Environmental pollution models.

This section will define a methodology to evaluate the environmental impact of the ports' activities with the use of the developed models:

- An overview of the modelling approach will be presented, introducing the relation between every modelling component.
- The methodology for the construction of each model will **not** be presented in this section, but in the subsequent dedicated – for each model – sections.
- The required data in order to feed each model will be presented in this section. Their availability and the methods to acquire them will be presented in this section.

#### 3.1.1. Objective and scope

The objective of the environmental management model is to **identify the inputs and outputs** of the energy demand and production model, the hinterland multimodal transport model and the environmental pollution model in order to **develop a modelling and simulation methodology taking into account the impact of the results of one model on another**. Thus, the scope of the environmental management model is to provide the project with the structure of the data types that will be used in the models and – following initial discussions with the PIXEL participating ports – assess the feasible level of detail that can be achieved through current data availability. Following this scope, some modelling of ports' activities and available data based on the current input of ports will be presented.

#### 3.1.2. Data source description

There are two different data sources to be used as input for initial modelling of ports' activities.

- **Static data coming from ports inventories.**
  - Facilities Management can provide lists of existing equipment containing information on machinery brand and type, power, type of fuel / energy used, consumption, throughput, environmental limitations (e.g. wind for cranes), etc.
  - Operations Management can provide information on logistics chains (scenarios) inside the port for the handling of cargo. This information can include machinery usage sequence, throughput of the whole operation, environmental limitations (e.g. heat for workers, rain for cereal handling, etc.).

- This type of data can be integrated at the models during the model creation manually by the end-user. This data will be store in the Information Hub and an interface will be developed to allow end-users to define them. However, during the port operation (and the model application), the users should be able to change these data in the model, should the items these data are referring at actually change. For example, if – in the future – a port decides to replace Straddle Carriers with Terminal Tractors for the transfer of containers between the dock and the container storage area, the user should be able to:
  - add the new Terminal Tractors in the equipment inventory of the model and
  - replace the Straddle Carriers in the corresponding scenario or discard the existing scenario and create a new one containing only the Terminal Tractors.
- **Dynamic data coming from ports IT infrastructure such as Port Management Information Systems (PMIS) or Terminal Operating Systems**
  - An example of this data can be the ships’ calls list. As far as PIXEL is concerned, such data can be retrieved through PMIS or specialized systems like VIGIEsip for GPMB. Using this call list, the model will be able to answer the question of when a cargo is expected to be handled. So, this list should contain data such as expected time of cargo (ship carrying the cargo) arrival or departure, amount of cargo, areas concerned (e.g. dock specification). This way of model data feeding will be named “Forecast Path” as it will be based on actual cargo handling forecast.
  - However as described in (Simon, 2019), this list can be substantially inaccurate as some ships’ calls may not be declared in the PMIS. For small and medium-sized ports, a large part of the ships’ calls is received only about 24 to 48 hours before the arrival of the ship. So, this list could be supplemented by a predictive algorithm evaluating the recorded cargoes treated by the port during a similar timeframe in the past based on seasonality of cargo shipments. This way of model data feeding will be named “Assessment Path” as it will be based on assessment of future cargo handling.
  - Furthermore, the user should be able to freely edit the list of considered cargoes. This data will be store in the Information Hub and an interface will be developed to allow end-users to define them. The customized cargoes list can be based on an imported csv or json file, or directly from “Forecast Path” or “Assessment Path”. This way of model data feeding will be named “What if Path” as it will allow the users to predict the impact of hypothetical cargo arrival or departure.

### 3.1.3. Links between port operation, activities impacts and emissions quantifications

The importance of the port sector in the development of the global commercial activity is vital. At present it is considered that *more than 90% of the world’s trade is carried by sea* (International Maritime Organization, 2019). As described in Deliverable No. 3.1 - Stakeholders and market analysis report the general activities of the ports can be distinguished as follows:

- Container and general cargo handling,
- Solid Bulk handling,
- Liquid bulk handling,
- Passenger transport.

All activities are related to air pollutant emissions in general as well as being an important source of environmental noise pollution. Furthermore, solid bulk handling has the risk of accidental release of bulk material to the environment and liquid bulk handling has the risk of accidental spills. Also, intensive maritime transport activities are related to abrasion of the sea ground, underwater noise, etc. Impacts of ports’ operations on the marine environment are limited to events usually of accidental origin and are not corelated to the supply chains operators. For example:

- Stormwater run-off from port (when not collected by stormwater network).
- Accidental leakages in loading and unloading of products.
- Accidental leakages in refuelling operations.
- Oil and motor fuel leakages from cranes, trucks, tractors, stackers, etc.
- Accidental discharges of chemical or hydrocarbon from deposits.

Therefore, releases of solid bulk, spills of liquid bulk and similar events are mostly accidental and they will not be modelled. Environmental air pollution is the top 2018 environmental priority (EcoPorts | ESPO, 2018) by the European port sector as a whole, followed by energy consumption. Although noise pollution is also a significant priority, the complexity of port’s infrastructure and lots of different activities in port lead to many sources that may contribute to the ambient noise of a port area agglomeration, so this matter is addressed in the Environmental Pollution Models section. Air pollution sources in seaports as far as activities are concerned are identified in the following table:

*Table 5: Air emission sources in ports (Srivastava, et al., 2011), (Darbra, et al., 2005)*

Source	Pollutants	Effects	Geographical Level
Dry bulk	Sulphur dioxide (SO <sub>2</sub> ), Hydrocarbons (HCs), Particulate matters (PM <sub>10</sub> , PM <sub>2.5</sub> ), Lead (Pb), Nitrogen oxides (NO <sub>x</sub> ), volatile organic compounds (VOCs) Ozone (O <sub>3</sub> ), Hydrogen fluoride (HF), Carbon monoxide (CO), Hydrogen fluoride (HF), Heavy metals (e.g. Hg, Pb, Cd etc.)	Human Health (acute and chronic)	Local, Regional and Global
Liquid bulk			
General cargo			
Cargo handling storage		Ecosystem (acute and chronic)	Local, Regional and Global
Vehicle and equipment maintenance			
Users Handling and storage of chemicals (non-bulk)		Greenhouse gas emission	Global
Fuelling and bunkering		Acid rain	Global
: Building and open area maintenance		Stratospheric ozone depletion	Global
Transshipment (Ro-Ro, Passenger, Container, ...)			
Ship movement			
Maintenance dredging & disposal	Long-range transport	Global	

Towing			
Mooring			

According to (Milošević, et al., 2019) and as far as equipment is concerned the main three air pollution sources associated with the activities mentioned above are:

- Ocean going vessels.
- Cargo handling equipment.
- Vehicles.

**Total emissions** for each source of pollution (equipment) will be calculated by using an equation of the following type:  $TE = A \times EF$

Where:

- TE= total emission
- A= activity rate
- EF= emission factor

### 3.2. Description of the overall methodology for the environmental management of port

The PIXEL modelling stack’s purpose is to transform raw data (from sensors, various computing devices and fixed lists of data) into useful and actionable information. To do this, the approach developed makes a clear distinction between two steps, as illustrated in Figure 13.

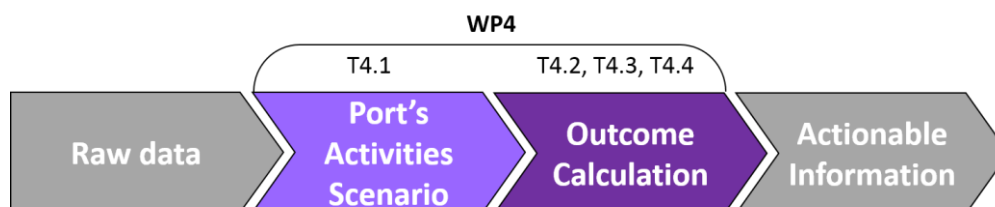


Figure 13: From raw data to actionable information, the PIXEL modelling approach.

The first step transforms the fed raw data into a Port’s Activities Scenario (PAS) which is a list of all the upcoming port’s operations with determined articulation across time. The second step calculates the outcome of the PAS on a certain time period (as energies consumption, pollutants emission etc.).

#### 3.2.1. Definition of a port activities scenario

Port activity is generated by incoming and outgoing cargoes transition into the port ecosystem. Therefore, PIXEL focuses on the cargoes handling from one area to another through machines. For each cargo, there are several ways to arrange transition operations between areas. A hypothetical combination of those transition operations (for one or more cargo) will be denoted thereafter as a **scenario** (Simon et al., 2019). That is why the main and central component of the PIXEL modelling approach is the **Port’s Activities Scenario** (denoted thereafter as **PAS**) modelling.



PAS modelling is able to describe all operations taking place within a port. However, there is a strong limitation for correct modelling: once an amount of cargo is stored in a warehousing area, its transition to the gate (outside of the port) will not happen automatically, but it is related to external factors such as suppliers' contracts, hinterland transport equipment availability, owners' warehousing capacity, etc. So, PIXEL will focus on cargoes handling between ships and storage areas. The forecasting of hinterland cargo handling will be based on predictive algorithms.

The Port Activities Scenarios will be used to link the different models and guarantee interoperability (i.e. outputs of multimodal transport model will be an input to air/ noise pollution models).

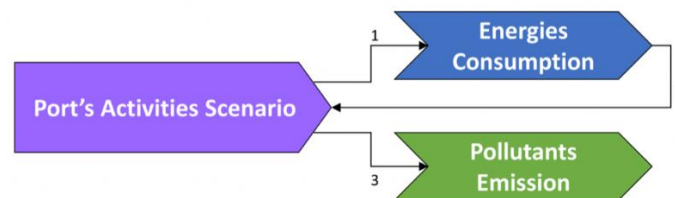


Figure 14: PAS and example of models' interoperability

### 3.2.1.1. What is a PIXEL scenario?

A PIXEL scenario is a set of data describing all the activities and the equipment participating in those activities that are taking place within a timeframe for a specific amount of specified cargo. As such, it allows the calculation of energy consumption, emissions quantifications and other externalities quantification.

A PIXEL scenario consists of:

- A call for the handling of an amount of cargo starting at a specified time.
  - A scenario (supply chain) applied on the above-mentioned call. The supply chain contains:
    - Machinery.
    - Areas.
    - General port considerations or restrictions.

**A default supply chain should be provided by the user, in case there is no direct correspondence between a cargo type and a supply chain.** This data will be store in the Information Hub and an interface will be developed to allow end-users to define them.

The following paragraphs define the data models for the modelling of a PIXEL scenario: a data model organizes elements of data and standardizes how they relate to each other and to real world entities. Having a common structure for modelling supply chain *allow to model different scenario*.

### 3.2.1.2. Involved data-models

In order to build the PAS, and to enable total integration of the following outcome calculation modules, an important work was done to identify and design suitable data-models. The data-models are the formal data structure definition that is used to represent an entity involved in the PAS modelling. This section provides an overview of each data-model with some example (based on the French GPMB use case and with huge collaboration of the energy model), dispatched into three indicative groups. A detailed presentation can be found both in appendix A and in the PIXEL's paper (Simon et al., 2019).

### 3.2.1.2.1. PAS

The call for the handling of an amount of cargo at a specified time will be originating by vessel calls (as they are described in 3.1.2). The procedure to transform such vessel calls into cargo queues will be described in 3.2.3.

Input: The input will be containing data related to:

- The ship's name and IMO number.
- The ship's estimated time of arrival and departure to the port and to a specific dock.
- The category or type of cargo that will be unloaded and/or loaded and the stakeholders related to that operation supplemented with a description regarding its inherent danger for handling.

This data can be obtained by the vessels' call list and by the FAL forms (if available to the user) as they will be transformed by the PMIS. It can be supplemented by past (historical) data in order to specify the exact type of cargo.

Output: The output will be containing data related to the port activities that will take place for the handling of the cargo of the input. It will apply the selected (by the PAS builder or the user) supply chain for the cargo(es) that will be handled for each ship.

### 3.2.1.2.2. Collections

The data of collections describe information relative to physical items used to produce port's activity. It is a description of the port and its operations. This data is mainly "static" as described in 3.1.2, i.e. the source of the data is the port's inventories. The provider of this data is the port itself: equipment manuals and brochures and areas descriptions can be provided mainly by the Facilities Management and logistics chains, stakeholders mapping, cargo cataloguing and port operations rules (that are described in 3.2.1.2.3) can be provided mainly by the Operations Management. However, the collection of this data can be a lengthy process since, as it has been observed during T4.1, these are not readily available. Finally, it is noted that data such as emissions factors or machinery emissions can be obtained from relevant literature (GloMEEP) or from databases. The collections of data are the following:

- **Machine**

This is a collection of the machinery used by the port's stakeholders in order to handle the cargoes operations. The characteristic of the equipment relative to the modelling of PIXEL is related to the following:

- Machine type: machine types are specified by the users and categorize the equipment per its function (e.g. cranes, forklifts, straddle carriers, etc.). This characteristic, coupled with the availability of a machine allows the model to either select alternative machinery (for the same stakeholder) or to select generic values for its throughput, consumption etc. if any of these is not available.
- Operator: In the European context, the equipment is usually not owned by the port authorities but by operators (i.e. Terminals, Agents, etc.). This characteristic forbids the model to choose equipment for handling cargo that is not related to a stakeholder.
- Throughput: This describes the efficiency of the equipment and is expressed in units of cargo that can be handled in a time unit.
- Speed: For moving machines (i.e. machines that are carrying cargo between two specified areas of the port), throughput is calculated as the amount of cargo that can be moved within the unit of time. So, specifying the speed of the equipment when loaded and when empty allows the model to calculate the throughput of the machine.
- Consumption: Regardless of whether the equipment operates on electricity or on fossil fuels (usually Diesel), this characteristic of the machine will allow the model to predict the energy consumed within the specified amount of time the machine will be operating and calculate

subsequently the air pollutant emissions of the equipment during its operation using *emissions factors* (see 3.2.2).

- Emissions: Emissions factors can be superseded by knowing the exact emissions of an equipment during its operation – usually this type of data is provided by the manufacturer.

- **Area**

Depending on the level of detail required by the user (port), the area data model can be:

- Generic (e.g. describing only one shore / ship unloading area and one warehousing area)
- More detailed (e.g. describing only one area per use, i.e. pier for cereals carrying ships, pier for container ships, etc., liquid cargo storage area, container storage area, etc.).
- Even more detailed (e.g. dock 1 of pier 1 for container ships, dock 2 of pier 1 for container ships, dock 1 of pier 2 for cereal carrying ships, etc., Liquid cargo tank 1, Liquid cargo tank 2, Cereal warehouse, Ore silo, etc.).

As the model is simulating energy consumption and movement of cargo, it currently does not require the areas' cargo capacity for capacity check and selection of different similar area for storage. If this option is requested in the future, it can be added to the model.

Compared to machines, areas have one key distinction: energy may be consumed even when no cargo is currently entering or exiting from it as is the case for thermal regulated tanks, constant lightning in warehouses etc. Obviously in most cases areas can be used by many different stakeholders.

The characteristics of the areas related to PIXEL are the following:

- Area type: Area types as defined by the user are a failsafe feature of the model that will not allow the user to handle cargo in areas not suited for this cargo. So, for example containers cannot be stored in oil tanks.
- Consumption: As noted above, consumption for areas is required in order for the energy model to calculate the energy consumed in these areas not only during cargo handling, but also constantly.

- **Supply Chain**

A collection of the activity data referring to the logistics chain linked to a cargo. It is composed of the following data:

- Operator: Same as for the equipment, the stakeholder that is operating the described supply chain. If for the same type of cargo there are more than one supply chains, one of the filters applied is the operator mentioned in the PAS Input.
- Cargo Type: the associated cargo type being handled of which the supply chain is describing.
- Areas of departure and arrival: the main function of sequences of equipment operating in a port is moving cargo from one area to another.
- Handling way: This can be used to describe different operations on the same cargo as for example whether the cargo is being loaded or unloaded from a ship.
- Operations: For each equipment involved in the supply chain, its operations are described. PIXEL provides the flexibility to distinguish between different modes (*types*) of operations of one equipment (e.g. initialization, normal operation, end of operation and machinery storage etc.) and describe them separately. Besides the machine and its type, the following are also described:
  - The type of the start or end of the machinery operation. For example, it is defined whether operation B will start as soon as the supply chain starts (or whenever it becomes available), or together with operation A, or after operation A has been concluded.

This can be related either to different machinery working sequentially or to the same machines entering different type of operation (e.g. initialization is followed by operation which is followed by storage).

- The duration of the operation. This can be given either directly (e.g. for machinery initialization – engine warm-up), or through a simple arithmetic operation between throughput and the percentage of the amount of cargo to be handled or between the speed of the machinery and the distance the equipment has to cover.
- Usability: The description of the working shifts during which the supply chain will be operating.

- **Cargo type**

A collection of the cargo types and their sub-types the port is handling specifying the cargo measurement units and the typical amount range for each cargo.

### 3.2.1.2.3. Rules

Rules are being used by the PAS builder in order to prioritise, check and map the cargoes and the supply chains. These are also specific to each port.

- **Priority**

Priority rules specify whether First In First Out (FIFO) rules apply, the priority order of each cargo type and the priority order for handling of hazardous cargo. This is used by the PAS builder in case a number of ships carrying cargo using shared equipment dock almost simultaneously at the port. Generally speaking, by setting the Priorities the issue of having N cargo types using 1 supply chain is tackled.

- **Mapper**

Mapping rules prioritize the supply chains for one cargo type, if there are more than one ways to handle it. Generally speaking, by setting the Mapping rules the issue of having 1 cargo type using N supply chains is solved.

## 3.2.2. Emissions quantifications

### 3.2.2.1. Air emissions

The quantification of air emissions resulting from port activities can be based in the use of emission factors (EF).

The average air emissions potential of equipment is quantified by using the following formulas:

$$E = A \times EF$$

$$A = FC / T$$

Where,

- E = total emission in kg/T
- A = the activity
- EF = emission factor (g/kg fuel),
- T = the working time in the port (h) of an equipment within the port,
- FC = fuel consumption (g/kWh).

## Diesel Fuel Consumption availability

The following air pollutants can be quantified:

Pollutant
Nitrogen Oxide (NO <sub>x</sub> )
Carbon Monoxide (CO)
Carbon Dioxide (CO <sub>2</sub> )
Methane (CH <sub>4</sub> )
Sulphur Dioxide (SO <sub>2</sub> )
Non-methane volatile organic compounds (NMVOC)
Particulate Matter 10 micrometers or less in diameter (PM10)

### Assumptions for diesel machines:

- Diesel machines fuel consumption is an almost linear function of their power output. The fuel consumption of a correctly tuned diesel machine ranges between 230 and 240 grams / kWh.
- Diesel machines are seldom operated at full power, due to issues of overheating, loss of power, etc. Most diesel engine operators operate them in a range between 50% and 70%. If no consumption is given for a machine participating in an activity, in PIXEL we assume, that cargo handling equipment will be operating in 70% of its full rated power, loaded cargo carrying equipment will be operating in 70% of its full rated power and unloaded cargo carrying equipment will be operating in 50% of its full rated power.

### 3.2.2.2. Emissions quantifications as inputs for PEI

The operational activities of the ports as modelled by PIXEL contribute to the build-up of an emission inventory for the calculation of the Port Environmental Index as shown in WP5 – T5.3 PEI development and described in D5.2 PEI definition and algorithms.

An emission inventory is a *collection of data presenting an emission of pollutant (to air) and related parameters* including (Van Aalst, et al., 1998):

- the location of the emission and the elevation of the release of the pollutant
- the time dependence, i.e. the certain time period during which the emissions are totalled
- the chemical properties of the pollutant
- the cause of the emission and its relation to human activity

By quantifying the emissions of air pollutants through the supply chain modelling, PIXEL is able to feed directly the PEI algorithms with emissions data related to operational activities of the ports. Furthermore, PAS aggregates the actions (operations) of a port within a certain time period and can make rough estimations for feeding PEI calculation (see deliverable D5.2 for more details).

## 3.2.3. How to build and use a port activities scenario for environmental management

The Port Activities Scenario is designed to be flexible in its adoption from different ports and for different cases. It is based in the following principles:

- **Modularity:** As described in 3.2.1, PAS will link different models and will provide data resulting from one model to the other(s).
- **Flexibility:** By being an interoperable hub of different models, PAS can allow the future development of additional models describing other ports' use cases.
- **Adaptability:** Being able to operate with varied amount and accuracy of data, PAS will provide results of varying certainty. Input data can range from generic areas and supply chains with dummy equipment to very detailed and specific descriptions of equipment, supply chains and working restrictions within the port.

In order to comprehend the modularity, flexibility and adaptability of the PIXEL solution, a full example of the PAS operation is described below.

### 3.2.3.1. Description of a full example: from a vessel call to a quantification of emission

The sequence of actions from a vessel call to a quantification of emissions is as follows:

1. A ship approaching a port sends a vessel call and a FAL form to the PMIS of the port.
2. The PMIS feeds the PAS with the PAS Input.
3. PAS considers:
  - a. The cargo.
  - b. The estimated time of arrival.
  - c. The port description.
  - d. The rules and priorities set before hand for the handling of similar cargo.

In order to create a supply chain queue.

4. The energy consumption corresponding to the PAS is calculated by the energy model.
5. With the use of emissions factors, the energy consumption calculated is translated to emissions quantifications by the PAS.
6. The emissions quantifications can be used by the Environmental Pollution Models.
7. The emission factors can be used to feed PEI data values (with simulated data) for its calculation.

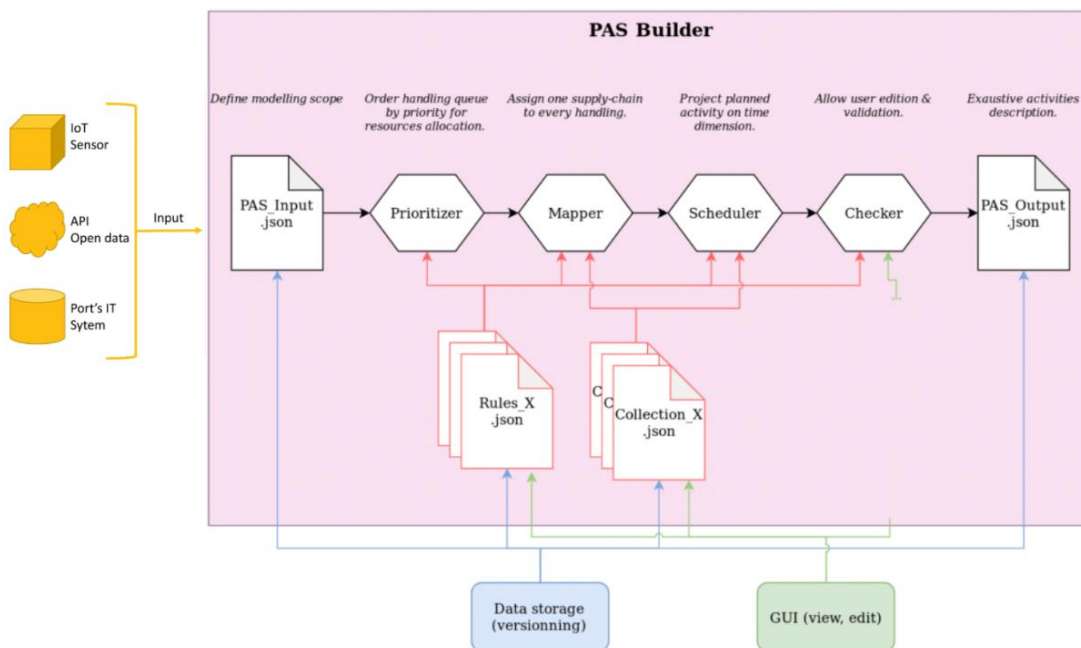


Figure 15: How to build a port activity scenario

### 3.2.3.2. Limits and suggestion of improvements

The limits of the model are mainly related to the limits of the automation in the ports industry.

#### 1. Data availability

Most of the data needed for the model are not easily available. Examples of data difficult to retrieve are:

- Cargo type: although cargo category (i.e. liquid bulk, dry bulk, containers, etc.) can be retrieved from the vessel call, the FAL forms that contain the cargo declaration of the ship are not usually notified to the port authorities; instead those are sent to the customs office. So, this type of data is available only after the cargo unloading operations are finished. Similarly, the exact type and quantity of cargo to be loaded to ships is not known well in advance before the cargo loading to ship operations commence.
- Equipment specifications: The port authorities are not owners of the cargo handling equipment. Depending on the cargo to be handled, various stakeholders are involved: for example, usually containers are being handled by terminal operators while bulk cargo is being handled by private companies. Consequently, there are no centralized inventories with cargo handling equipment and their specifications, and it will remain so as different entities are normally not willing to share data.
- Data availability issues can be handled by following a Minimum Viable Product approach and work with available data, or with data that can be retrieved by averaging similar data from other ports. However, this could decrease the model output accuracy (leading to great uncertainty and just giving an order of magnitude of the results). Also, manual data imputation can lead to model manipulation, so as to produce favourable results.

#### 2. Lack of supply chain description

A special data availability issue appears if, for instance for a specified cargo type, supply chain is not described in the model. This can be resolved by describing a default supply chain (defined by ports through GUI) to be used for all cargo types within a cargo category, however this will lead to loss of detail in the model output.

#### 3. Use of different supply chains for one cargo type

Different stakeholders (private companies, terminal operators) can be using different equipment to handle the same type of cargo. Depending on the equipment availability, even the same stakeholder can choose to temporarily modify the supply chain that will actually be used to handle cargo. Such decisions can be based on equipment unavailability, managerial or financial factors, etc.

This limitation can be handled by resolving to the use of a default supply chain (if available), however, same as for lack of supply chain description, this will inevitably lead to loss of detail in the model output. In the future, a better way to handle this limitation will be through the use of predictive algorithms based on the data feedback to the system regarding the actual supply chain that was elected in similar cases.

#### 4. Timing uncertainty

The cargo handling operations within a port are grouped in two phases. For cargo unloading from a ship these phases are:

- Phase 1: Cargo is unloaded from the ship and is transferred and stored in a temporary storage area (yard, tank, warehouse, etc.).
- Phase 2: Cargo is loaded from the temporary storage on to hinterland transportation vehicles (trucks or wagons) and is being transferred out of the port.

For cargo loading on ships the phases are similar.

Although the same modelling approach can be used for both phases, there is an unspecified amount of time between the two phases: cargo can stay within a port for an unspecified amount of time before it leaves the port. Furthermore, the cargo can be split between different companies before it leaves the storage area.

Thus, the current modelling approach is focused only in the handling of cargo between the ship and the storage area. In the future, predictive algorithms can be used to predict the slack time between the two phases of cargo handling.

## 5. Level of accuracy

As explained in (Simon et al, 2019) *depending of the purpose of modelling and the expected precision, input data could be less or more detailed. Thus, ports can use PIXEL models with comprehensive data (detailed model and low uncertainty), screening data (some local input and external data leading to a significant uncertainty) and scaled data (average and non-specific input data leading to great uncertainty and just giving an order of magnitude).* In order to make comparisons between the cargo handling efficiency of different ports, or the cargo handling efficiency of the same port across different time spans, the level of accuracy must be similar.

To surpass such limitations, a relatively rich database consisting of data from different users will be developed over time, thus the detail of data will be increased.

## 3.2.4. Requirements for integration of the port activities scenario in the PIXEL architecture

### 3.2.4.1. Data requirements

The data that will be collected will be fed into the system in the form of json files. JSON (JavaScript Object Notation) is a widely used lightweight data-interchange format written in text format which is used by applications to parse data and generate output that will be fed to the next function.

The json files that will be used for the model are the following:

Port description (ressources) data files. These data files will be created based on manual input by the users. Readers should note that the data models have been defined and should fulfil by ports.

- Collection\_AREA.json – file containing the area data of the port.
- Collection\_CARGO-TYPE.json – file containing the cargo types that will be handled by the port.
- Collection\_MACHINES.json – file containing the port equipment and their specifications.
- Collection\_SUPPLY-CHAIN.json – file containing the descriptions of the supply chains to be used by the port.

Port Activities Scenario files:

- PAS\_Input.json – input file generated by the Port Management Information System which is based on vessel call and past data collected.
- PAS\_Output.json – file containing the port activities that will take place based on the PAS\_Input.json and PAS\_Input\_extended.json

Rules files:

- Rules\_MAPPER.json – file containing the rules for mapping supply chain (priority supply chains and default supply chains).
- Rules\_PRIORITIZER.json – file containing the cargo priorities rules.

### 3.2.4.2. System Requirements

The application is written in Python 3.6 with pipenv, so the CPU, RAM and HD requirements are low: low-end modern computers capable of internet browsing should be able to run the PAS builder.



### 3.2.4.3. Visualization, triggers and KPIs

The Graphical User Interface (GUI) will be used for:

- Inputting initial data (creation of Collection\_AREA.json, Collection\_CARGO-TYPE.json, Collection\_MACHINES.json, Collection\_SUPPLY-CHAIN.json):

Area					
Identification					
ID		NCA_Pellets		Suitable_Cargo_Type	
Area_Type		Non Covered Area		Pellets	
Consumption (kWh)					
In Use					
Lights	With_sunlight				
	Without_sunlight				
	Thermal_Regulation				
	Other				
Not In Use					
Lights	With_sunlight				
	Without_sunlight				
	Thermal_Regulation				
	Other				
Comments					
Date	Time	Text			

Machine					
Identification					
ID		Loader_IC_01		Suitable_Cargo_Type	
Machine_Type		Loader (Low Capacity)		Terminal Hangar	
Model				Non Covered Area	
Owner				Berth	
Terminal				Crushed glass	
Picture		Please specify a url of the uploaded picture		Paper pulp	
				Other Dry Bulk	
Specifications					
Initialization (min)					
Energy Regular Diesel					
Current_State Available_Now					
Usability					
Working_hours					
Start					
End					
Max_Consecutive					
Wind (km/h)					
Weather_limits					
Rainfall (mm/h)					
Temperature (°C)					
Capacity Units		units			
Capacity					
Speed (km/h)					
Default					
Loaded back ratio (%)					
Consumption Units		/100km			
Consumption					
Emissions					
Capacity					
Speed (km/h)					
Empty					
Loaded back ratio (%)					
Consumption					
Emissions					
Comments					
Date	Time	Text			

Scenario		
Identification		
ID		Import_Packked_Wood
Cargo_Type		Packed wood
Quantity Units		t
Placement		
Area Start		Area Finish
Name		Name
Berth_03		NCA_PackedWood
Equipment		
Machine	Sequence for next machine	Route length
Terminal Lighting	>	0
Rail Crane	>	0
Loader (Medium Capacity)	>	500
Loader (Low Capacity)	>	500

Figure 16: Example of GUI for initial data

- PAS output manual editing: before the final issuance of the PAS, the user should be able to edit the output.

The screenshot displays a web-based interface for editing PAS (Port Area Schedule) data. It is organized into three main rows, each representing a different 'STOPOVER' (ID: 20190465, 20190483, 20190800). Each row contains several interactive panels:

- STOPOVER Summary:** A panel on the left of each row showing key identifiers like ID, ETA/ETD ports, and BOAT information.
- HANDLINGS Table:** A central table with columns for Agent, Operator, Way, CONSTRAINT, DOCK, and CARGO. It lists specific operations like 'Déchargement' and 'Chargement'.
- DOCK Details:** Panels for each dock (Area\_1, Area\_2, Area\_4) showing Area\_ID, ETA\_dock, ETD\_dock, and other parameters.
- CARGO Details:** Panels for each cargo item showing Dangerous status, Type (e.g., Céréale, Mais, Blé), Amount, and Label.
- METADATA:** A panel on the right of each row for adding comments and viewing history.

Figure 17: Example of GUI for PAS editing

- User live notification will be handled through message boxes. The final visualization of the PAS output will be similar to a Gantt chart.

The screenshot shows a Gantt chart titled '[Project Name] Project Schedule'. The chart is organized into three main categories (1, 2, 3) and lists various tasks and sub-tasks. Each task is represented by a horizontal bar indicating its duration and progress. The chart includes a header with project details like 'Project Start Date' (1/29/2018), 'Project Lead' (Ted Harris), and 'Display Week' (1). The x-axis represents time, with columns for days of the week and dates. A red vertical line is positioned at the current date, which is 12 Feb 2018.

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1	[Task Category]	-	-	-	-	-	-
1.1	[Task]	[Name]	Mon 1/29/18	Fri 2/02/18	5	100%	5
1.2	[Task]		Sat 2/03/18	Wed 2/07/18	5	60%	3
1.3	[Task]		Thu 2/08/18	Sun 2/11/18	4	0%	2
1.4	[Task]		Thu 2/01/18	Sun 2/04/18	4	75%	2
1.4.1	[Sub-task]		Fri 2/02/18	Sat 2/03/18	2	50%	1
1.4.2	[Sub-task]		Sun 2/04/18	Tue 2/06/18	3	50%	2
1.5	[Task]		Mon 2/05/18	Fri 2/09/18	5	0%	5
1.6	[Task]		Sat 2/03/18	Fri 2/09/18	7	0%	5
1.7	[Task]		Sat 2/10/18	Fri 2/16/18	7	0%	5
2	[Task Category]	-	-	-	-	-	-
2.1	[Task]		Sat 2/10/18	Tue 2/13/18	4	0%	2
2.2	[Task]		Wed 2/14/18	Fri 2/16/18	3	0%	3
2.3	[Task]		Wed 2/14/18	Fri 2/16/18	3	0%	3
2.4	[Task]		Sat 2/17/18	Thu 2/22/18	6	0%	4
2.5	[Task]		Fri 2/23/18	Sun 2/25/18	3	0%	1
3	[Task Category]	-	-	-	-	-	-
3.1	[Task]		Sat 2/10/18	Tue 2/13/18	4	0%	2
3.2	[Task]		Wed 2/14/18	Fri 2/16/18	3	0%	3
3.3	[Task]		Wed 2/14/18	Fri 2/16/18	3	0%	3

Figure 18: Example of GUI for PAS output

The PAS builder will be triggered on user demand or with the creation of a new PAS\_Input.json by the PMIS.

#### 3.2.4.4. Training requirements

As a reasonably powerful and flexible tool, some aspects of PAS builder's setup and use can be too complex to be done without some training. Initial setup should be carried out by the software development personnel in cooperation with the ports' facilities and operations management personnel. Alternatively, wizards and example files can be used.

Everyday operation should be monitored and input by the ports' environmental and operations personnel. In that case, the training required will be focused on these personnel also with the provision of user's manuals and tutorials.

#### 3.2.4.5. Transferability requirements

The application will be transferable for reasons related to technology advancement, expansion of ports, etc. Such transferability is ensured with the json files used by the application are text based and not binary.

## 4. Energy demand models

For operational actors in ports, energy efficiency is an important issue from environmental and economic perspectives. In time, ports would like to be able to optimize their energies flows. Our aim is to model *the port's energy demand and production to provide information about energy availability, reliability and efficiency*. In order to do so, a prerequisite is to quantify both energies consumption and production in order to access to energies balance in the context of complex industrial processes. To do so, the energy model deploy three complementary components addressing those needs (see Figure 19):

1. Quantify the energies consumption corresponding to a PAS.
2. Predict the local photovoltaic electricity production for a given period.
3. Estimate the resulting electricity net balance between electricity consumption and production in the port area.

In the following sections we describe each of the three model's components.

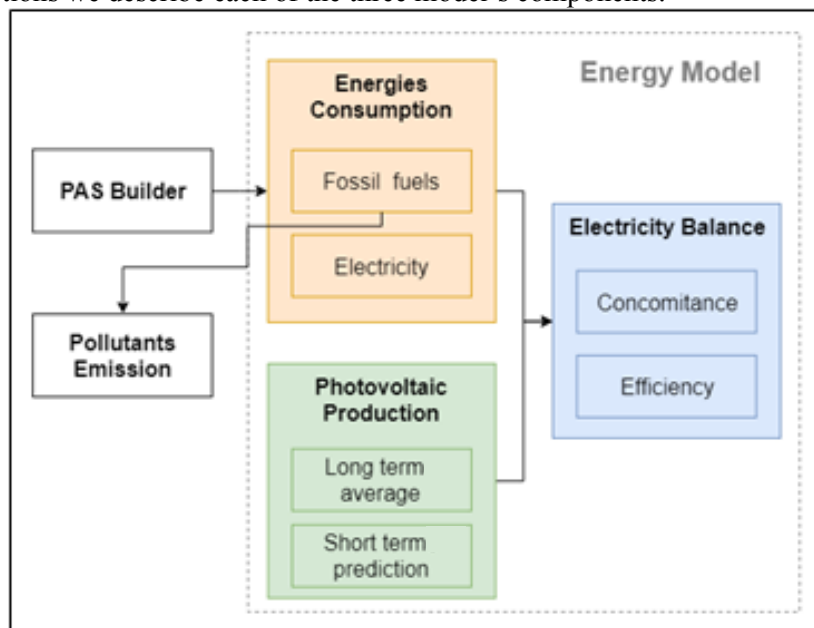


Figure 19: Energy model components diagram

### 4.1. Energy model description

#### 4.1.1. Consumption module

This first module aims to enable ports to calculate their energies consumption related to their activities. **Since energy demand at the port is directly proportional to the movement of cargo, we give special focus on this specific task.** The energy demand will be modelled according to a fixed scenario using the PAS.

##### 4.1.1.1. How the model works

For every considered cargo that is transiting inside the port, the corresponding sequence of operations across time is provided through the port activity scenario (PAS) described in the previous section. This time series is the module's input. For each operation, the duration, the machine's energy type and its unit consumption values are available (from input and parameters combination). For each operation, the energy cost is calculated as the product of atomic operation's duration multiplied by its machine's unit consumption. Note that the energy consumption independent to the PAS (e.g. buildings with thermal regulation) could also be considered and add to the energy's consumption time-series. Then for every energy's type, all the consumptions occurring during

the same timeframe can be summed to get the corresponding total consumption. The sequence of all those timeframes constitute the energies consumption time-series.

#### 4.1.1.1.1. Inputs

##### **Port's Activities Scenario**

The mains input for the energy model is the port activity scenario as a list of ordered operation that take place in the port over a certain period of time. This input is described in the previous section. A lot of work has been done in collaboration between tasks T4.1 and T4.2 to be able to generate a port activity scenario that could easily be used as an input for the energy model. The data model for the port activity scenario is a conjoint work and a huge focus on interoperability have been done.

#### 4.1.1.1.2. Parameters

##### **Machines, Buildings and lights specifications**

These parameters are described in the previous section and have to be fulfilled by port agents and/or terminal operators.

#### 4.1.1.1.3. Outputs

The output consists of information addition into the PAS. For every operation, the energies consumption is inserted as a new sub-field.

### 4.1.1.2. Limitations and assumptions

The module design presents the advantage to scale its output's precision and accuracy to the available data. This allows ports and users to choose their optimal position between [simple inputs – lower accuracy] and [richer inputs – higher accuracy]. This also implies that the module does not have a known default inaccuracy or error rate. Beside the impact of missing or erroneous data (i.e. incomplete boats' call list in the PAS or wrong machine's energy unit consumption), inaccuracy is also induced by a simplistic port's description through the parameter. As an example, grouping several atomic operations into a unique supply-chain description, or using unique machine's energy consumption independently of the cargo type, will decrease module accuracy.

Furthermore, the module design brings strong control to the final user in order to adapt to frequent needs of adaptation to special case. Several checks and warning are provided, but end-user have strong responsibility on output coherency and accuracy.

Finally, models intrinsically incorporate simplification that brings incompressible errors. Indeed, many factors can impact operator and machine efficiency and thus the energy consumption. As an example, temperature can substantially modify the viscosity of a fluid and therefore pumps' efficiency, two distinct machines drivers may have different efficiency.

The Energies Consumption module's output accuracy can be tested and validated by two approaches. First, the opinion of several experienced port operators could be requested. To do so, each expert would setup an arbitrary PAS (corresponding to his cargoes handling expertise) and give an appreciation to the module output. Second, the module output can be confronted to effective measurement. As an example, to quantify the whole activities' electricity consumption modelling, a PAS corresponding to actual activities during a billing period can be use. The ratio of modelled consumption versus actual billed amount can be used as an accuracy quantification tool.

Note that GPMB will be able soon to provide aggregated electricity consumption data in real time. This could allow a thorough inspection of the model's accuracy. In particular to study the results of the model on a fine temporal resolution such as hour. This work will be done in WP7.

## 4.1.2. Photovoltaic Production module

This module aims to predict the electrical energy that could be produced by the port using photovoltaic installation. For now, GPMB have no PV (neither other PIXEL ports) systems already installed and their goals is to have tools in order to make a decision for investment. For the modelling purpose we have distinguished two distinct needs and contexts. A first scenario is to size an installation or calculating depreciation, with a more long-term perspective. The following section describe this module. A second scenario is to pilot a power grid considering the incoming electrical production. This corresponds to continuously predicting next hours to days' production. This is addressed through a specific predictive algorithm (T4.5) that will be described in deliverable D4.4.

### 4.1.2.1. How the model works

This module aims to provide typical or “most probable” electrical power produced by a photovoltaic power plant. The module is based on the PVGIS<sup>1</sup> European tool's API (see Figure 20). This online tool is a free and high-quality photovoltaic production calculator, described as follow:

*“This tool makes it possible to estimate the [...] energy production of a PV system connected to the electricity grid, without battery storage. The calculation takes into account the solar radiation, temperature, wind speed and type of PV module. The user can choose how the modules are mounted, whether on a free-standing rack mounting, or integrated in a building surface. PVGIS can also calculate the optimum slope and orientation that maximizes the yearly energy production. [...]”*

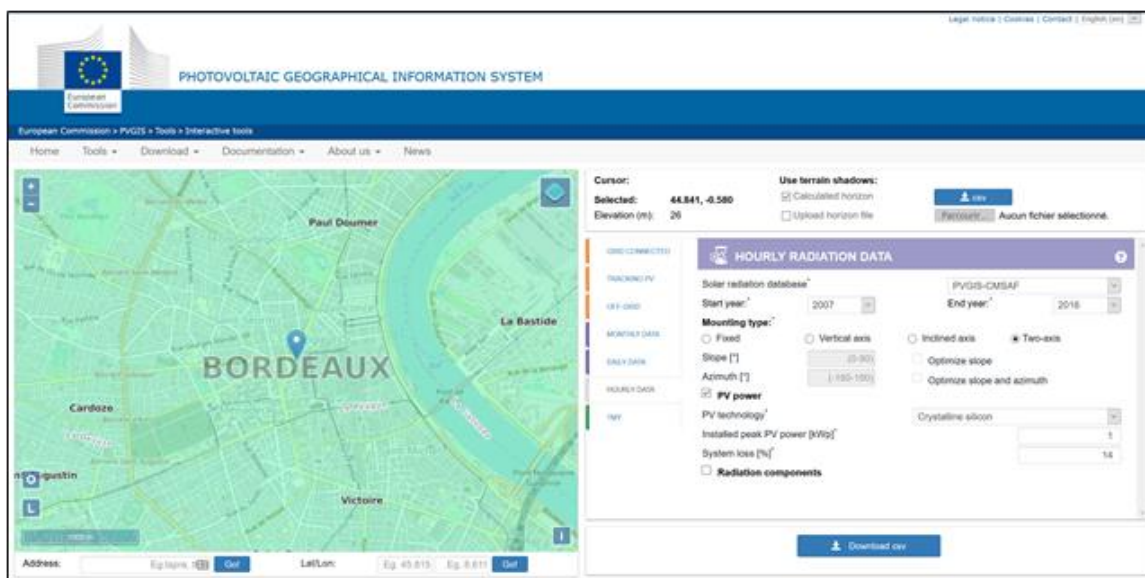


Figure 20: Screenshot of the European PVGIS open-source tool, used for potential photovoltaic production prediction

It gives to users a valuable irradiance and weather database and calculation module, several options covering most of the needs and a convenient panels' characteristic database for easy use. From the several tools proposed, the “Hourly Solar Radiation and PV Data” is used for PIXEL through its API connection. It provides fine time resolution (every hour) estimated electrical production for a specified photovoltaic power plant setup,

considering the historical (or reconstituted) irradiance and weather conditions. Once controlled, these data can be aggregated to get typical value (e.g. mean hourly production during a summer day, extreme variation and so on, see in the following section).

## 4.1.2.2. Data

### 4.1.2.2.1. Input

From a formal point of view, the input data are net irradiances, temperature and wind temporal series. But those inputs are internally managed by the PVGIS tool, without user involvement. More details can be found in the extensive PVGIS documentation and associated research papers.

### 4.1.2.2.2. Parameters

#### Photovoltaic power plant characteristics

A first set of parameters concerns the installation's site. Localization (longitude & latitude) and use of terrain's horizon (neighbourhood's shadows) will drive the maximal irradiance. A second set concerns the panels themselves. Beside technical considerations as weight, maximum power voltage and other, the panel technology (as thin films, mono or multi crystalline silicon, CIS or CdTe, with or without anti-reflective coating) will drive the efficiency (conversion rate and thermal drift). A third set of parameters concern the whole panels rack. Number and size of panels, base type (fixed or 1D/2D tracking system) and other (DC/AC conversion ratio, system consumption) will drive the resulting electrical power output.

Furthermore, PVGIS propose several options as considering batteries, import shadows data and other. For a complete description, see PVGIS user's manual<sup>1</sup>.

### 4.1.2.2.3. Output

Beside some header and footer information, the output is a csv file containing the electricity power production as a time series, as presented in table 5, where  $EPV$  is the PV system power (W),  $G_i$  is the in-plane irradiance (W/m<sup>2</sup>),  $As$  is the sun elevation (deg.),  $Tamb$  is the ambient temperature (deg. C),  $W10$  is the wind speed (m/s) and  $Int.$  indicate if the solar radiation values are reconstructed (when the value is 1)

Table 6: Illustrative module's output

Date	EPV	G <sub>i</sub>	As	Tamb	W10	int.
20070101:0055	0.00	0.00	0.00	13.04	3.34	0
20070101:0155	0.00	0.00	0.00	12.70	3.34	0
20070101:0255	0.00	0.00	0.00	12.35	3.34	0
20070101:0355	0.00	0.00	0.00	12.01	3.34	0
20070101:0455	0.00	0.00	0.00	11.68	3.45	0
20070101:0555	0.00	0.00	0.00	11.35	3.57	0
20070101:0655	0.00	0.00	0.00	11.01	3.68	0
20070101:0755	3.25	12.57	1.45	11.09	3.99	0
20070101:0855	167.82	205.20	9.49	11.16	4.30	0

<sup>1</sup> [https://re.jrc.ec.europa.eu/pvg\\_static/en/manual.html](https://re.jrc.ec.europa.eu/pvg_static/en/manual.html)

### 4.1.2.3. Limitations and assumptions

The calculated "typical" values are reconstituted from averaging 2007 to 2016 historical irradiance and weather records. These values do not consider any weather forecast (or "new" historical) data that would be available when PVGIS is used. So, for any user and at any time, the same value will be predicted for a site and a given moment. Thus, the model's output's accuracy relies on the fact that averaging the calculated value for the specific installation would be representative of the actual photovoltaic power plant installation.

In the PIXEL project's context, there is no photovoltaic installation to test PVGIS prediction against actual values. Then the test and validation part will be limited to PVGIS performance reported in bibliography. Beside some limitation due to decreasing accuracy when considering time period shorten than a year, the tool provides an accuracy that meet the ports expressed requirement.

*"Both PVGIS and PVWatts seem to predict relatively accurately the produced energy with annual deviation  $-4$  and  $-6.5$  %, respectively. The prediction of the produced energy during winter and summer worsens with deviations around 7 to 8 %"* (Psomopoulos, 2015).

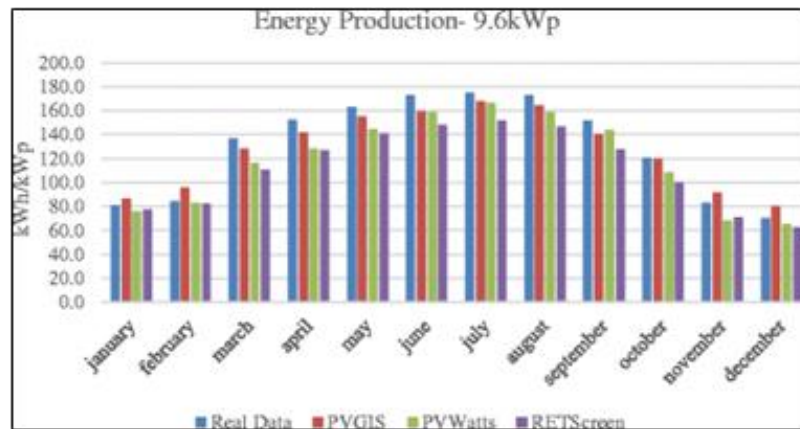


Figure 21: PVGIS accuracy illustration (Psomopoulos, 2015)

*PVGIS approach provides analysis and assessment of in-site solar energy resources and predicts with good accuracy the potential of PV systems in term of electricity production. We find that annual total power generation of the micro-power is slightly higher than that initially expected at the installation stage and actually measured. The yearly predicted and measured power production values agree to about 2 %. However, individual monthly production can have larger discrepancy.* (Suri, 2006).

### 4.1.3. Balance module

To optimize energy in ports, there is a strong need to convert energy consumption and production data into actionable information and useful knowledge. As an example, this module can trigger a notification when it predicts that the net electrical consumption will reach its annual peak. As this annual peak is an important element for the electrical subscription price calculation, operators may choose to spread on few hours the most consuming operations to avoid this peak. By doing so, the electricity subscription price can be reduced every year. Another example is to enable users to characterise the combination of temporal cycles. From the daily and yearly photovoltaic production profile, to the consumption seasonality due to the cargoes' types distribution across time (e.g. supply-chain consumption's temporal shift from fertilized import to cereal export).



### 4.1.3.1. How the model works

This module will transform data from Energies Consumption and Photovoltaic Production modules' output, then it will also have the port as perimeter. Three data treatment are realised:

1. The electrical net balance time-series is calculated. This correspond to the amount of required electrical power minus the photovoltaic production occurring during the same timeframe. To do so, the energies consumption and photovoltaic production time-series are aligned. This is done while preserving atomic characteristics for thematic aggregation (i.e. machine's type, cargo's type, dock and so on), in order to provide a powerful energies data inspection tool.
2. Each time-series is analysed for its periodicity. A score of periodicities and the typical time interval is researched. If a time-series is composed of several sub-time-series (i.e. the total electrical consumption), then the relative importance of each of its periodic component is calculated for ranking.
3. Energy efficiency is calculated. That is to say, for every operation, the ratio of energy consumption on cargo amount. For electrical machines, this is done both with and without considering the photovoltaic production (deduced of energy consumption). Here again, this is done while preserving atomic characteristics for thematic aggregation.

### 4.1.3.2. Data

#### 4.1.3.2.1. Input data

The two inputs are respectively:

- Energy consumption time-series (from the Energies Consumption module's output),
- Electrical production time-series (from the Photovoltaic Production module's output).

#### 4.1.3.2.2. Parameters

If alerts are to be issued when threshold values may be exceeded, these thresholds must be provided as parameters.

#### 4.1.3.2.3. Output

This module has three types of outputs.

##### **Graph**

The data transformation allows to present useful information and knowledge, presented to the end-user through graph. A set of preselected graphs are automatically generated in a "dashboard" form. Furthermore, other custom graphs can be built by the user through a convenient interface.

##### **CSV files**

The raw and transformed data can be download as csv files.

##### **Notifications**

If notifications conditions are setup, then when targeted value reach the threshold value, a notification is sent. This behaviour corresponds to a monitoring and short-term prediction use of the tool.

### 4.1.3.3. Limitations and assumptions

A limitation concerning this module is a potential errors summation from the two time-series inputs. Furthermore, for net balance calculation, if one of the time-series inputs has no value to match a timeframe of the second time-series, a data completion has to be undertaken. This can introduce error in the net balance time-series calculation. Similarly, to the consumption module, the balance module will be tested and validated by expert users in stress-test conditions. This will be done in WP7 during the integration phase. In particular, the whole Energies Model’s output for a specifically configured PAS will be compared to available measurement.

## 4.2. Requirements for integration in the PIXEL architecture

### 4.2.1. Data requirements

The data necessary for Energy Management model proper functioning are pointed out in each of the three modules description.

### 4.2.2. System Requirements

System resources requirement seem lightweight both in terms of storage space and computing power (CPU & RAM, no need for GPUs). As an indication, the first tests on modest computers<sup>4</sup> showed that generation of outputs is done in less than half a second. However, other tests more representative must be performed for precise quantification in WP7 with collaboration of WP6. In particular, the following impact have to be studied:

- a more representative mass of information (PAS size, number of specifications for port's supply-chain, machines and area),
- the duration of information exchange between the model's modules, and if necessary, with the Information Hub (through the Operation Tools).

### 4.2.3. Visualization, triggers and KPIs

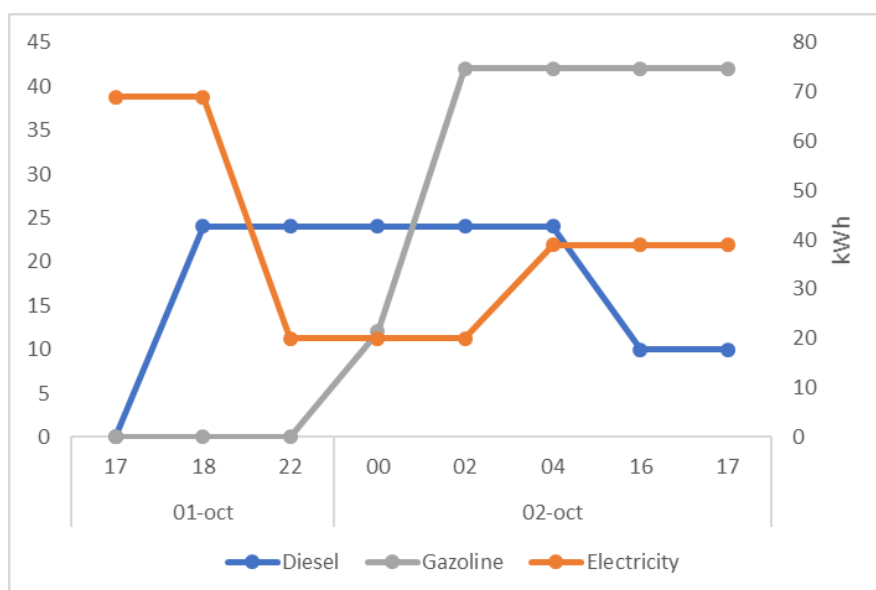


Figure 22: Energies consumption across time (lines, 2 vertical axis, one series for each energy type).

The precise definition of the most useful graphs for the energy dashboard conception is still undergoing and will be clarified during the integration phase in WP7. For illustration purpose, some propositions are presented here.

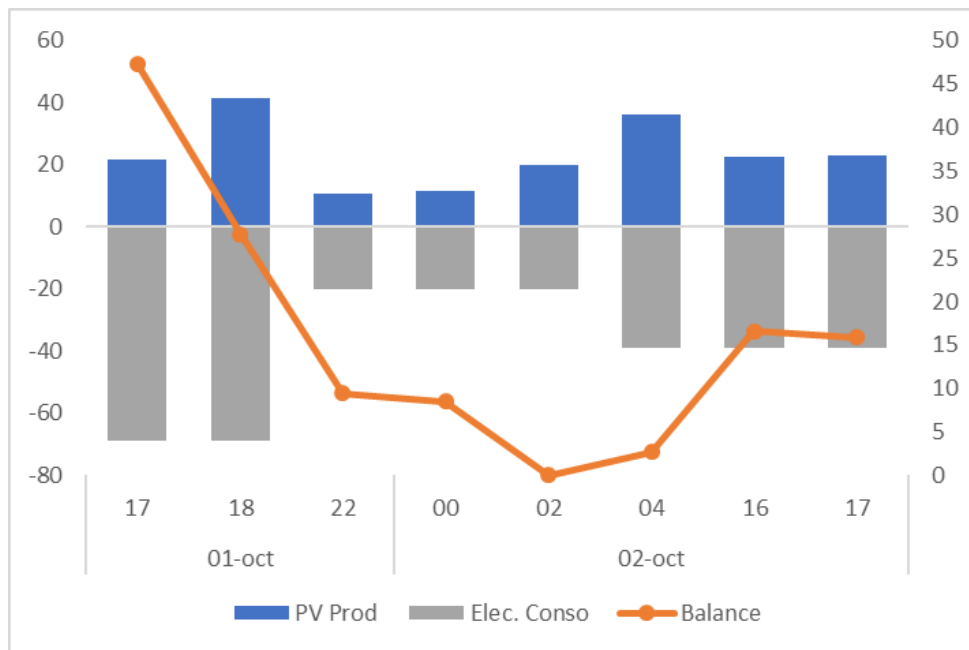


Figure 23: Electricity balance (as a line) across time, with consumption and production as histogram on background (2 vertical axis)

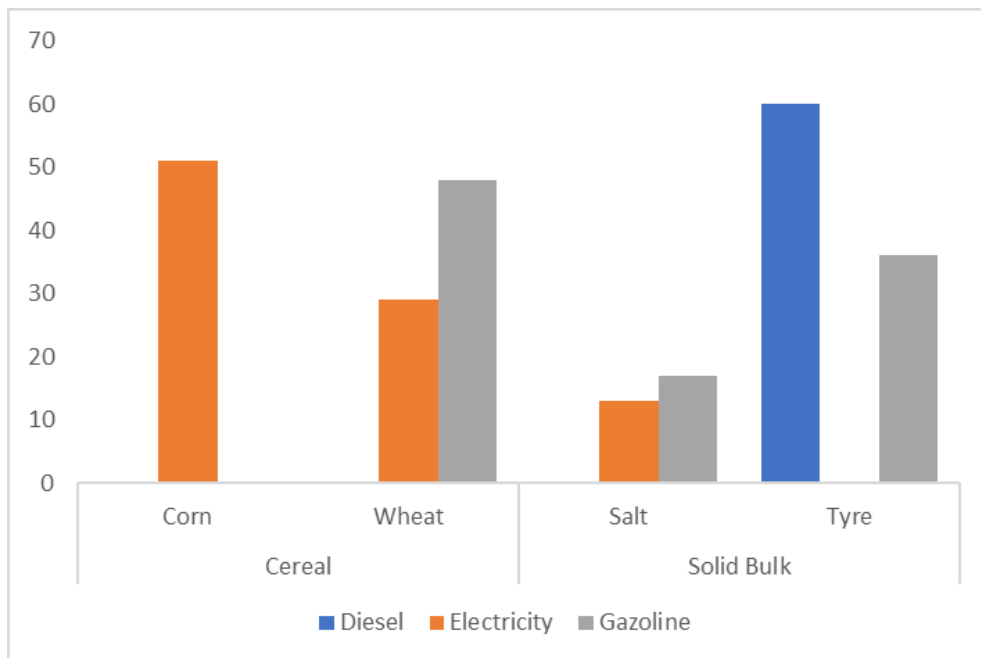


Figure 24: Mean net energies consumption (with fossil fuels stacked) for every cargo segment & type pair.

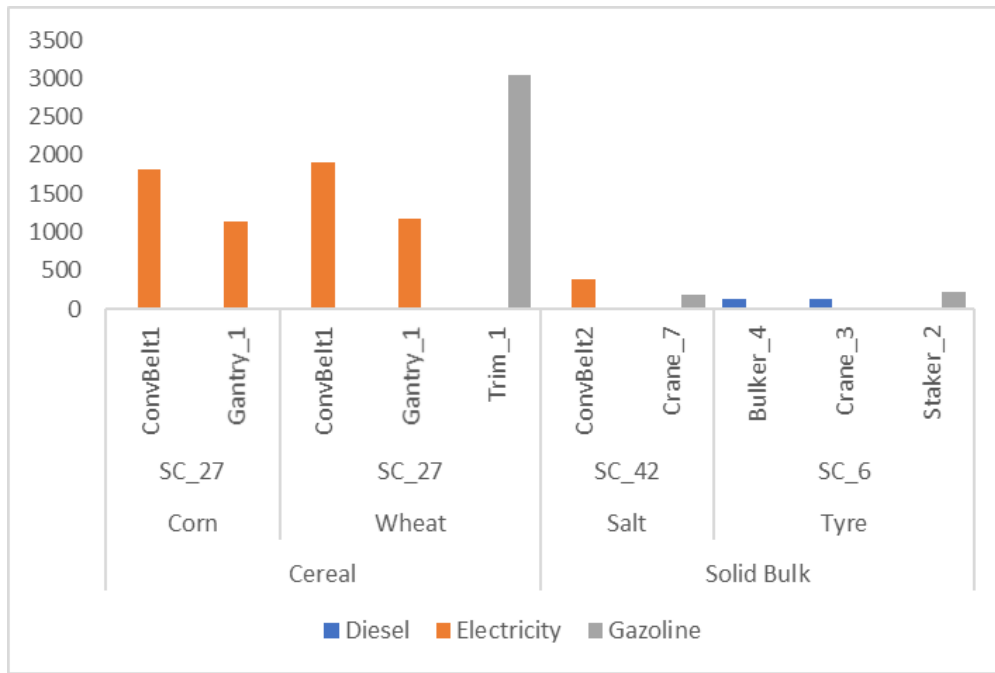


Figure 25: Machine efficiency (energy consumption per ton) boxplot for every cargo segment & type & supply-chain triplet



Figure 26: Periodicity: TSA seasonal decomposition

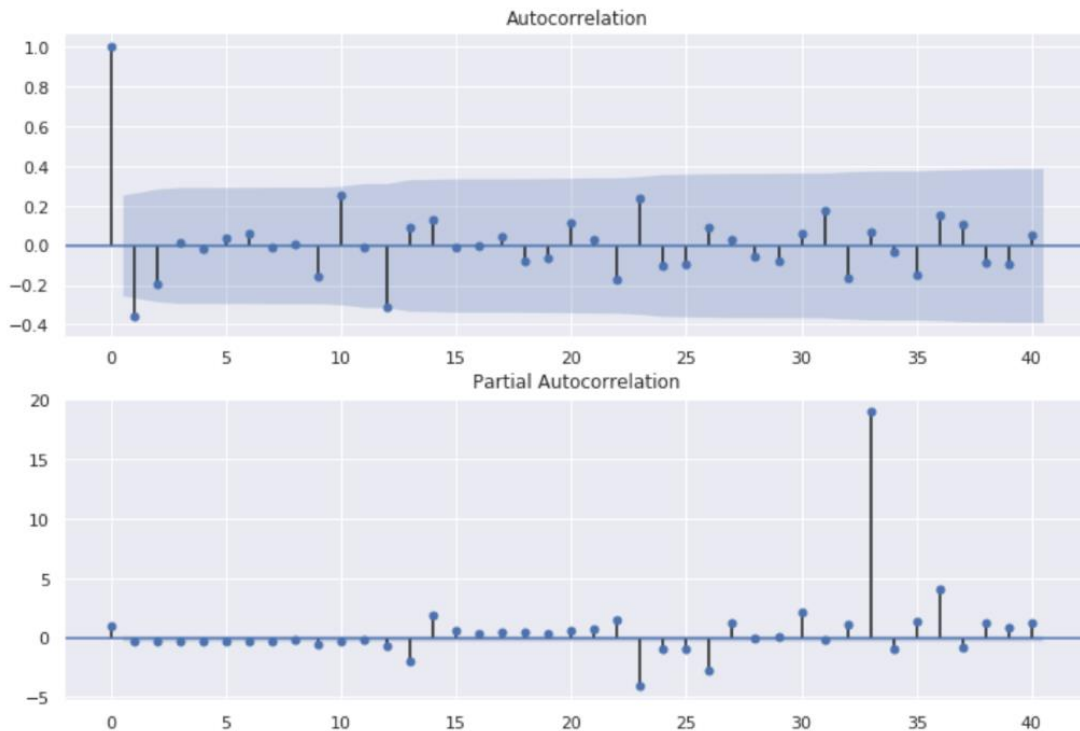


Figure 27: Periodicity: Autocorrelation and partial autocorrelation

#### 4.2.4. Training requirements

The biggest part of the required user's expertise is relative to the PAS builder usage. That is to say, generating the proper PAS for which the energy consumption time-series have to be established. However, some training seems necessary for:

- getting comfortable to interpret all information provided by the dashboard;
- getting autonomous for deep data exploration with complementary graph tools;
- setting up the notification criteria.

#### 4.2.5. Transferability requirements

The deployment of the model from one port to another is relatively easy, since it is accompanied by few adaptations. As a matter of fact, most of the parameter's configuration is reported at the level of the PAS Builder model. However, some configuration files remain to be adapted, such as the characteristics of a theoretical photovoltaic station, or automatic alerts.

Note that in order to adapt the model's output's confidence interval (optional parameter), each port must determine the available measurements and establish an ad hoc calibration (empirical determination).

## 5. Hinterland multimodal transport Model

### 5.1. Introduction and scope

The operational activities of the Port of Monfalcone are mainly the unloading of goods from the ships and the handling of the cargo in the port warehouses/stocking areas. The main cases within the port of Monfalcone are:

- (i) the goods unloaded from the ship are stocked in the port areas;
- (ii) the goods unloaded from the ship are directly loaded in the truck;
- (iii) the trucks enter in the port to load the goods already stocked in the port.

The pier of Monfalcone port is public, so it is a resource shared between the port's operators. In addition, general services are supplied by different subjects that have specific attributions over the port (Port Authority, Maritime Authority, Police, Customs Agency, etc.) in accordance to the current legislation.

The traffic management of the Monfalcone Port is not linked with other actors of the Regional territory due to the incomplete monitoring system of the freight traffic in the Friuli Venezia Giulia Region, in particular:

- i) no common regional plans;
- ii) no interoperable information systems between the regional stakeholders (included Monfalcone Ports and SDAG) causes a reduced use of the railway and inland ports services with the consequent congestion of the ports areas and of the motorway and urban roads with a highest risk for the citizens' mobility;
- iii) only some port areas digitally managed;
- iv) no prediction plan to avoid congestion events;
- v) no analysis on how to reduce the environmental impact of road transport, especially related to special goods such as "slabs".

This trend could be modified using a system that put in communication and cooperation all stakeholders of the Region in order to increase the knowledge on the typology of the traffic (from, to, what, when) and to manage the traffic using all available resources (ports, inland ports, railway) in order to reduce the impact on the traffic, addressing the traffic toward multimodal transport, in particular railway, and improving the services provided to the truck drivers using all regional resources such as inland port service provider.

The model should be able to collect data needed and transform it in a trucks flow inside port area and indirectly in a slot parking demand in order to identify when and how to trigger events to fulfil pilot's aims. Hinterland multimodal transport model should also be able to collect and normalize useful data to calculate port's PEI. To do so we're going to analyse a specific scenario in order to see how the environmental impacts improve using different transport mode (rail instead road) carrying goods from Monfalcone port to destination.

### 5.2. Available data

#### 5.2.1. Typology, validity, reliability, completeness, accuracy and integrity of data

There are a lot of different data needed to be gathered in order to define a model able to fulfil the transportation use case and to give an answer to pilot's objectives list.

We need to collect the data shown below:

- Vessel calls
- Planned arrivals and departures of vessels (in a time interval);
- Planned arrivals and departures of trucks (in a time interval);
- Real time parking occupancy;

- Real time situation on port's gates.
- Weather situation on port premises;
- Road traffic situation (include Authority's order);
- Complexity of loading and unloading activities in order to estimate time truck will be stuck inside port area (e.g.: unloading activities requiring special equipment or large temporary storage area influencing trucks flow inside port area);
- Historical data related to arrivals and departure of vessels;
- Number of available parks in SDAG;
- Data of SDAG transit (in and out per hour).

**Vessel calls:** We need to extrapolate the number of vessels ingoing and outgoing for every single day at least for the week incoming. For each vessel a set of data is associated like identification of vessel, type of goods carried, estimated time of arrivals and estimated time of departure, number of tons carried;

**Planned arrivals and departures of trucks:** We need to extrapolate the number of trucks ingoing and outgoing for every single day at least for the week incoming. For each truck, a set of data is associated: i.e. identification of trucks (plate number), type of goods carried (the most important thing is to differentiate between ADR and other goods), estimated time of arrivals and estimated time of departure (even the time of stop inside port area could define the need of a slot inside parking area).

**Real time parking occupancy:** This data, coming from a camera that ASPM is going to install over parking (deployment and integration in the scope of WP7), give us real time information about the currently slot parking availability. This is the most important data in order to estimate not only real time occupation but even to identify slot availability trend line (historical record of parking slot availability).

**Real time situation on port's gates:** By using a camera installed over port's gate we are able to estimate if there is a congestion or an important flow entering port's gate. This information gives us an idea of how is going to change parking lot demand in a short term;

**Weather situation on port premises:** These data are useful to understand if trucks incoming to ASPM is going to have the possibility to reach it by using road infrastructure. This is not only a real time alert (is snowing and the road to ASPM is closed or completely congested) but even a forecast alert (the weather forecast tell us is going to strong snow in the next 8 hours, it's very likely road Authority is going to stop heavy traffic in the next hours).

**Road traffic situation (include Authority's order):** Sometimes it happens that the corresponding traffic authority is obliged to close some roads due to car accidents or some planned maintenance work. This information is useful to understand if a set of trucks planned to arrive in a certain time interval will really arrive or not, helping decision maker to choose if divert trucks traffic to SDAG. Even trucks exiting from port using that road could stop inside the port (and then inside parking area);

**Historical data related to arrivals and departure of vessels:** The analysis of historical data related to arrivals and departure of vessels should pay attention to some correlation between certain vessels loading and unloading and the availability of parking slot. Model will be able to transform this correlation in a parking slot demand.

**Number of available parks in SDAG:** in order to create synergies between Monfalcone Port and SDAG in case of congestion or expected congestion of the port, it is necessary to know if it is possible to push the truck traffic toward SDAG

**Data of SDAG transit (in and out per hour):** an updated information about the truck's transits in SDAG can help to forecast of Port traffic and Regional Road traffic.

### 5.2.2. Source provider

Each set of data depicted will be collected from a specific source. Sometimes data are available and managed by port's Authority (ASPM and SDAG are the stakeholders participating as partners in PIXEL acting as pilot owners for this model). In those cases, we have full availability to use them inside the project without specific authorizations. Other times data are not managed by port's Authority and we need to ask other stakeholders involved inside port area (such as import/export companies, port operators, ...). In these cases, we could have some problems using them inside project (privacy problems).

**Planned arrivals and departures of vessels:** PMIS and PMIS 2 systems are the platforms from which we are going to download data related to vessels. Currently, these data can be consulted by Monfalcone Port by a special account to access to the PMIS portal. Within PIXEL these data will be used by web services or using the data available on Monfalcone Port website.

**Planned arrivals and departures of trucks:** these data cannot be used as there are not available but can be forecasted with a prediction from both PMIS and SILI systems (both actual and historical) or ASPM sailing list database.

**Real time situation on port's gates:** This data is monitored by SILI system.

**Wheatear situation on port premises:** OSMER data can be used <http://www.osmer.fvg.it/mare.php?ln=#/>.

**Road traffic situation (include Authority's order)** Provided by predictive algorithms

**Historical data related to arrivals and departure of vessels:** PMIS or ASPM sailing list database

**Number of available parks in SDAG:** will be used by a service that extract data from Information System used in SDAG.

**Data of SDAG transit (in and out per hour):** will be used by a service that extract data from Information System used in SDAG.

## 5.3. Modelling of the evacuation of slab to the hinterland and modelling of the modes of organization of the port passage

### 5.3.1. Description of the model

The model will help to understand if a different traffic management has a positive impact on congestions issues, citizens risk on the road and environmental impacts. The main result that will be reached is an effective decision support tool to optimize the re-routing of trucks from the Port towards SDAG or other infrastructures, and so facilitate the staff working in both entities.

The model mentioned above has been split in two sub models, one related to intermodality way of transport applied on slabs traffic between ASPM and Aussa Corno industrial district, the other one related to traffic and parking inside port premises and the possible rerouting to SDAG. We are going to call the first one "intermodality sub model" and the second one "traffic sub model".

There are a lot of different data (each kind of data will be in deep analyse in the following chapters) to consider, to harmonize, clean and aggregate in order to trigger events.

So, once we gathered all data needed (INPUT DATA) we have to process them (DATA PROCESSING) so to have a set of clean data (OUTPUT DATA).

With the aim to keep the model as generic as possible and have the possibility to use it for other pilots and small and medium ports with similar issues, three steps are needed:

- **PARAMETERIZATION:** each specific condition related to model universe (road distances, rail distances, multimodal transportation nodes, goods transported, public authorities rules...);



- **DATA AGGREGATION:** each specific reality has its own data coming from different sources. In order to trigger events sometimes we need to aggregate them (to reroute a truck from ASPM to SDAG we need to know at the same time data coming from traffic source, data coming from parking occupancy sensors and so on...)
- **THRESHOLDS IDENTIFICATION:** In order to trigger events, we need to define when the event must be triggered. For instance, we can decide to divert a truck coming to ASPM when parking occupancy is greater than 90%. So 90% is the threshold beyond which trucks will be diverted.

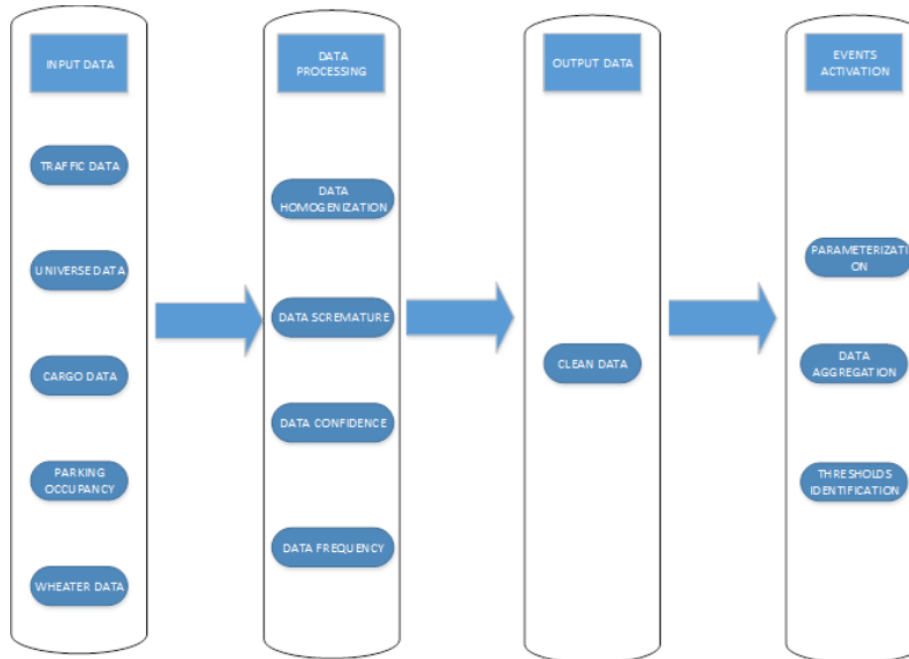


Figure 28: Hinterland multimodal transport model

Managing these 3 steps allows to use a model as a DSS (decision support system) for stakeholders involved, and at the same time allows to calibrate the model for different situations, different universes (different pilots, different ports).

In terms of emissions quantification, we are going to focus on how emissions, inside and outside port’s premises, change due to different transport modes. In the following, we analyse a “use case” that is currently in a start-up period. Steel slabs arriving at ASPM by shipping with the aim to get to "Aussa Corno" industrial district (Metinvest Trameal, Technosider are the enterprises involved in this business). There are 2 potential scenarios:

**Scenario 1:** “Steel slab” arriving to Monfalcone’s port by shipping. Slabs are handled by cranes and put into trucks.

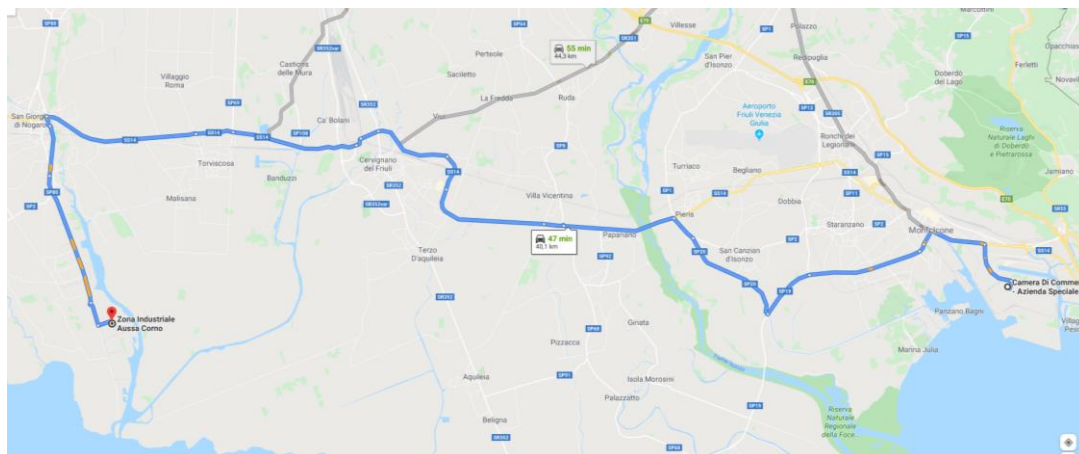


Figure 29: From Monfalcone’s port to “Aussa-Corno” industrial district by road

Trucks are driven by roads from Monfalcone Port to “Aussa Corno” industrial district (almost 40 km away) passing through a dozen of small and medium villages making growing up congestion traffic jam and potential accidental crash (social security decrease). Most important is the heavy weight of the cargo strongly damaging road infrastructure during truck’s trip causing very high social costs.

**Scenario 2:** “Steel slab” arriving to Monfalcone’s port by shipping. Slabs are handled by cranes and put into a cargo train.

Trains are driven by rail from Monfalcone Port to suburban Monfalcone train station (by using a train with diesel engine) and then to “Aussa Corno” industrial district (almost 40 km) by using electric locomotive without passing through a dozen of small and medium villages, avoiding the growing up congestion, traffic jam and potential accidental crash (security decrease).

So there is a first part of the railway track, 10 km long, where a diesel locomotive produce pollutants to deliver cargo from ASPM to Monfalcone urban train station, then there is a second part of the railway, 30 km long, where an electric locomotive deliver cargo from Monfalcone urban train station to “Aussa Corno” industrial district producing almost no pollutants or at least nothing even comparable (it’s possible to indirectly calculate the pollutions to create the energy needed to deliver cargo, but a lot of unknown variables are involved) with the amount of pollution produced by diesel locomotive.

The emissions produced by railways arise from combusting the fuel in an internal combustion engine.

Consequently, the principal pollutants are those from diesel engines, i.e. similar to those used in road transport.

These are principally CO<sub>2</sub>, PM (including BC<sub>2</sub>) and NO<sub>x</sub>, plus to a lesser extent CO and hydrocarbons, together with SO<sub>x</sub> and heavy metals originating from the content of fuel in sulphur and metals, respectively

So the benefits brought by multimodality approach will be the difference between the amount of pollutants produced by delivering by trucks and delivering via rail. The second element is calculated only taken into account the first part of the railway track.

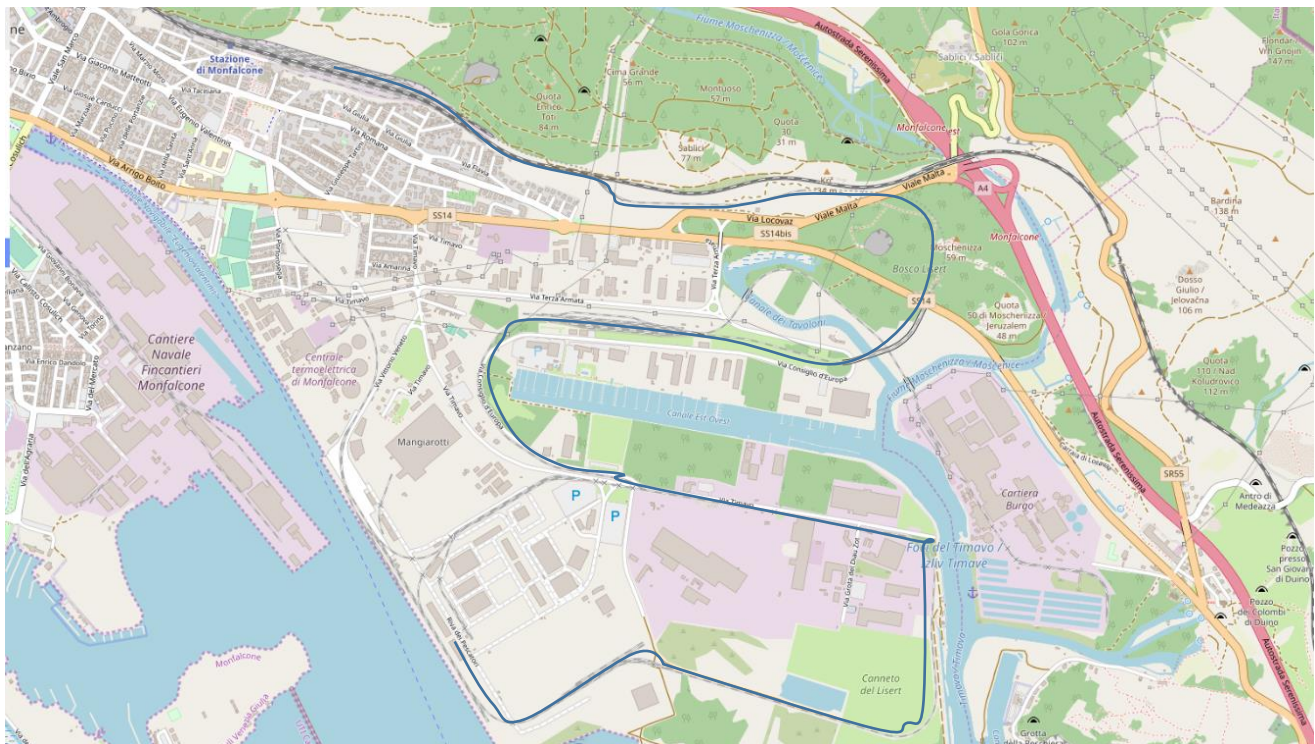


Figure 30: From Monfalcone’s port to suburban Monfalcone train station

In order to evaluate the model in the best possible manner, the pollution made by trucks in terms of CO, NO<sub>x</sub>, PM, ... emissions, we are going to use Copert method (<https://www.emisia.com/utilities/copert/documentation/>, to interpolate data from experimental tests).

Day Emission will be function of road length (Km), number of trucks involved by day and emission factor (each kind of vehicle has its own emission factor depending on kind of fuel, weight, model, traffic and so on, but we are going to use a standardised diesel truck emission in order to simplify).

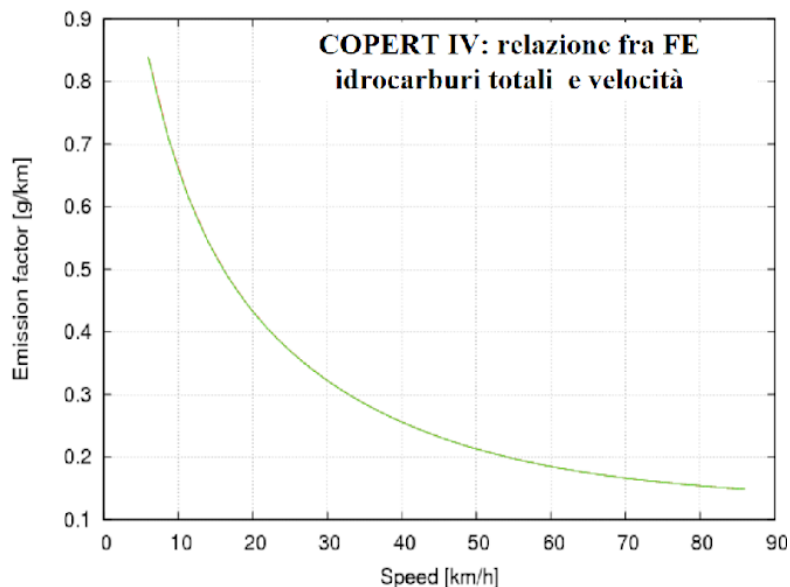


Figure 31: Illustration of COPERT IV Methodology

As one can see from the figure above the more traffic is the lower will be the speed of the trucks. Lower speed implies higher emissions. This is true not only for trucks involved in the transportation but for all vehicles involved in that traffic area. All study related to traffic system shows emission factor is function of speed. In particularly EMEP/EEA air pollutant emission inventory guidebook 2019. So, reducing trucks carrying goods by road reduces pollution directly (we have not trucks on the streets polluting the area) but even indirectly, reducing traffic jam and congestion the average speed of the whole vehicles involved on the streets will be higher and at the same time emissions will be lower.

Due to the weight of a single slab (almost 15 tons each) the transport agent is able to load only 1 slab (2 is maximum but in that case the transportation is not ordinary no more and they must ask for permissions to authority in order to access to road infrastructure) for a single truck. This business involves not less than 130 trucks per week.

### 5.3.2. Limitations and assumptions

The model should show ASPM how to use resources in order to cope with traffic congestion, weather, etc. that can affect the parking occupancy and then the port operations and thus the environmental impact. To be included in this modelling:

- Traffic flows;
- Provision of ships arrival;
- Road congestion;
- Data coming from the SILI system (road status, how many trucks passes through the SILI gate (1 in ASPM, 1 in SDAG, other throughout the region));
- Data coming from the video cameras system (occupancy sensor).

The model is going to operate inside a predefined universe involving:

- Port of Monfalcone;

- Hinterland hub (SDAG);
- Suburban Monfalcone’s train station;
- Aussa Corno industrial district (slabs use case final destination).

So, every data involved in the model concerns an area about 30 km of ray including the 3-spot mentioned above. Thus, we consider every parameter needed (traffic load, trucks, vessels, pollutions, ...) as inside the system or outside the system depending on where the parameters are measured or estimated. Therefore, the only events considered will be events that happen within the model universe.

### 5.3.3. How the model works

To estimate the global pollution produced by road delivery we need to know how a single truck pollutes during the trip from origin (ASPM) to final destination (“Aussa Corno” industrial district)

$$\text{Linear traffic equation: } E=N*L*EF$$

- E=Emissions per week (in terms of NO<sub>x</sub>, PM<sub>10</sub>, CO);
- N=number of trucks involved in the business in a single week;
- L=Length of the path between origin and destination;
- EF=Emission factor (it depends on type of vehicles, type of engine, weight carried on...)

Applying the algorithm into scenario emissions factor will be use the estimated global pollution per week. For example, considering a diesel truck we have these EF values:

- NO<sub>x</sub> = 6.444 mg/km; CO = 1.101 mg/km...
- Setting the round trip length to 80 km and considering 130 trucks per week we estimate the following NO<sub>x</sub> global emission:
- $E=80*130*6.444=67 \text{ Kg of No}_x \text{ (weekly)}$

Same process could be applied for other kinds of pollutants. All these elements should be very useful in order to better identify port’s emission due to traffic.

The model will help to understand if a different traffic management has a positive impact on congestions issues, citizens risk on the road and environmental impacts. The main result that will be reached is an effective decision support tool to optimize the re-routing of trucks from the Port towards SDAG or other infrastructures, and so facilitate the staff working in both entities.

The model mentioned above has been split in two sub models, one related to intermodality way of transport applied on slabs traffic between ASPM and Aussa Corno industrial district, the other one related to traffic and parking inside port premises and the possible rerouting to SDAG. As stated before, we are going to call the first one “intermodality sub model” and the second one “traffic sub model”.

#### 5.3.3.1. Intermodality sub model

Intermodality sub model will be able to identify pollutant emissions and in doing so to ease PEI calculation. The emissions related to the different transport mode of the slabs can be considered in the PEI and it is one of the data mentioned in PIXEL Deliverable D5.2 “PEI Definition and Algorithms v1”. In terms of emissions quantification, we are going to focus on how emissions, inside and outside port’s premises, change due to different transport modes. In the following, we analyse a “use case” that is actually in a start-up period. In the following figure is it possible to see 2018’s slabs moved inside ASPM.

In order to evaluate in the best possible manner, the pollution made by trucks in terms of CO, NO<sub>x</sub>, PM, ... emissions and comparing it with that produced by diesel locomotive, we are going to use Copert method to calculate trucks emissions and Tier 2 EMEP/EEA emissions factors for “line haul locomotive” to calculate diesel locomotive emissions<sup>2</sup>.

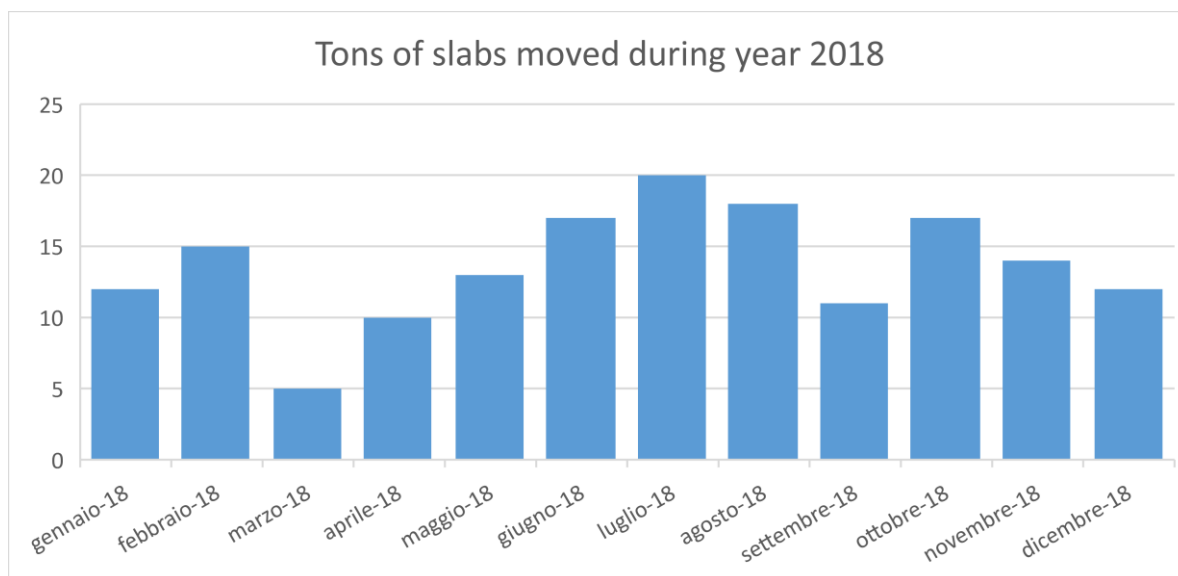


Figure 32: Tons of slabs moved in Monfalcone port during 2018

### 5.3.3.1.1. Trucks pollution calculation

Regarding trucks, day emission will be a function of road length (km), number of trucks involved by day and emission factor (each kind of vehicle has its own emission factor depending on kind of fuel, weight, model, traffic and so on, but we are going to use a standardised diesel truck emission in order to simplify). The same equation as the one presented in section 5.3.3 is used.

The more the traffic is the lower will be the speed of the trucks. Lower speed implies higher emissions. This is true not only for trucks involved in the transportation but for all vehicles involved in that traffic area. So, reducing trucks carrying goods by road reduces pollution directly (there are no trucks on the streets polluting the area) but even indirectly, reducing traffic jam and congestion the average speed of the whole vehicles involved on the streets will be higher and at the same time emissions will be lower. Due to the weight of a single slab (almost 15 tons each) the transport agent is able to load only 1 slab (2 is maximum but in that case the transportation is not ordinary no more and they must ask for permissions to authority in order to access to road infrastructure) for a single truck. This business involves not less than 130 trucks per week.

Applying the algorithm into scenario emissions factor will be use the estimated global pollution per week. For example, considering a diesel truck we have these EF values (see table below):

Table 7: Average emissions factor split by type of vehicles and type of road

Vehicles	Type of road	Specific fuel consumption	SO <sub>2</sub>	NO <sub>x</sub>	COV	CH <sub>4</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> O	NH <sub>3</sub>	PM2.5	PM10	PTS	CO <sub>2</sub> eq	Precurs. O <sub>3</sub>	Tot. acidif. (H+)
		g/km	mg/km	mg/km	mg/km	mg/km	mg/km	g/km	mg/km	mg/km	mg/km	mg/km	mg/km	g/km	mg/km	g/km
heavy vehicles > 3.5 t	Highway	170	3,4	4.174	159	32	1.090	513	21	5,5	131	168	223	520	5.371	91
	Extra urban roads	194	3,9	5.311	232	34	1.302	585	23	5,5	161	211	270	593	6.855	116
	Urban roads	240	4,6	6.966	361	61	1.778	720	22	5,3	206	265	324	728	9.055	152

<sup>2</sup> <https://www.emisia.com/utilities/copert/documentation/>

Setting the round trip length to 80 Km and considering 130 trucks per week we estimate the following NO<sub>x</sub> global emission:

$$E=80*130*6.444=67 \text{ Kg of Nox (weekly)}$$

### 5.3.3.1.2. Train pollution calculation

Regarding trains, day Emission will be function of fuel consumptions, and Tier2 emissions factors for line haul locomotive and number of trains involved by day.

There are several aspects to consider: Tier 2 method identifies pollution for km in an indirect way. All the tables related to this method show emissions produced per kg of fuel consumed, so we need to know fuel consumed from ASPM to Monfalcone train urban station. European Environment Agency provides a table showing fuel consumptions for different locomotive type (see it below); so knowing distance and average speed we can figure out transport time needed from ASPM to Monfalcone train urban station.

**Fuel consumption for different locomotive types**

Category	Fuel consumption	Units
Line-haul locomotives	219	kg/h
Shunting locomotives	90.9	kg/h
Railcars	53.6	kg/h

Figure 33: Fuel consumption for different locomotive types

Considering an average speed of the train, from ASPM to Monfalcone train urban station, equal to 15 km/h and knowing distance to cover is equal to 10 km, we find out trains arrive to station in 30 minutes (0,5 h). So now it is possible to apply algorithms using the table below.

Table 8: Tier 2 emission factors for line-shunting locomotives

**Table 3-3 Tier 2 emission factors for shunting locomotives**

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
SNAP (if applicable)	080201	Shunting locs			
Technologies/Practices	Shunting locomotives				
Region or regional conditions	NA				
Abatement technologies	NA				
Not estimated	SO <sub>x</sub> , Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NO <sub>x</sub>	54.4	kg/tonne	27	85	Halder et al. 2005
CO	10.8	kg/tonne	2	18	Note 1
NM VOC	4.6	kg/tonne	1	8	Note 1
NH <sub>3</sub>	10	g/tonne	0	0	Note 3
TSP	3.1	kg/tonne	0.75	5	Note 2
PM <sub>10</sub>	2.1	kg/tonne	0.53	4	Halder et al. 2005
PM <sub>2.5</sub>	2	kg/tonne	0.5	4	Note 2
(*) N <sub>2</sub> O	24	g/tonne	0	0	Note 3
(*) CO <sub>2</sub>	3190	kg/tonne	726	5335	Carbon balance
(*) CH <sub>4</sub>	176	g/tonne	41	297	Note 1

Let’s apply Tier 2 method to calculate NOx production, for instance, for a single train delivering goods to Aussa Corno Station. Trip distance considered is 20 km (round trip) cause, as written before, we are not going to consider pollutions provided by electromotive.

Taking into consideration the table above we see that diesel locomotive produce 54,4 kg of NOx for each ton of fuel consumed. But we know as well that a “shunting locomotive” consumes 90,9 kg of fuel per hour (0,091 tons). So, NOx produced by a single train is:  $0,091 * 0,5 * 2 * 54,4 = 2,48$  kg.

We also know that each train convoy deliver, plus or minus, 500 tons of slabs when each truck, for an ordinary road delivery, carry on only 15 tons of slabs. Then we can say that to carry on 500 tons of slabs using intermodality (train) produced 2,48 kg of NOx in the atmosphere all around hinterland, and especially in port premises. To carry the same amount of slabs via road using trucks we are going to produce, using “Average emissions factor split by type of vehicles and type of track” table and considering, to simplify, to drive only inside highway:  $500 / 15 * 0,004174 * 80 = 11,13$  kg.

So even now we are able to compare that simple result telling us trucks method pollute, in terms of NOx emissions, almost five time more than train method for this specific scenario.

### 5.3.3.1.3. Multiscenario analysis

In this section different path and modality of transport will be investigated in order to better understand what the real situation is, which are the alternatives and where we would like to arrive. Trying to sum up what has been written in the previous pages we could make a table with different “situations” and how these situations change pollutant emissions. There are several different paths to reach “Aussa Corno industrial district” starting from ASPM.

- *Via route using trucks (1):*
  - 1a – Starting from ASPM and passing through Monfalcone city and other smaller villages (40 km);
  - 1b - Starting from ASPM and using highway till “San Giorgio di Nogaro” exit (45Km);
- *Via rail using a combination of diesel and electric locomotive (2):*
  - 2 - Starting from ASPM, switching at Monfalcone train suburban station, and reaching “Aussa Corno industrial district”.

There are also different situations in the way slabs are carried on by using only trucks or only train transportation mode (**scenario “all or nothing”**).

Analysing this scenario, we are able to understand what we are going to pollute using only trucks for 2 different paths and what we are going to pollute using only trains. We use 2018 data because we already have all those data, we will try to guess 2019 trend later on.

Table 9: Pollutant emissions “all or nothing” scenario

2018 Pollutant emissions multimodal transportation model scenarios - slabs use case -all or nothing								
	NO <sub>x</sub>	CH <sub>4</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> O	NH <sub>3</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>
Year 2018	kg	kg	kg	t	kg	kg	kg	kg
Scenario "all or nothing" path 1.a	42 883,0	332,1	10 759,4	4 559,1	155,8	37,5	1 284,4	1 662,7
Scenario "all or nothing" path 1.b	32 698,2	244,8	8 391,0	3 827,8	150,5	38,0	1 009,7	1 301,5
Scenario "all or nothing" path 2	15 647,5	51,0	3 129,5	924,4	7,0	2,9	580	609

It is peculiar that some emissions are particularly lower when using the trains (CH<sub>4</sub>, N<sub>2</sub>O) meanwhile some others are more comparable (NO<sub>x</sub>, PM<sub>10</sub>). Anyway, trains emissions are lower than trucks as expected.

This is an ideal scenario because reality is that 380.000 tons of slabs are carried on via ships, 230.000 tons of slabs are carried on via trains and the rest (1.500.000-380.000-230.000=890.000) are carried on via trucks. It's almost impossible to calculate emissions by ships from ASPM to “Aussa Corno industrial district” because there are a lot of different ships transporting slabs, and we do not know engine features of each of them and are almost impossible to collect them. However, the work done in relation with Port Activities Scenario can help us to estimate this.

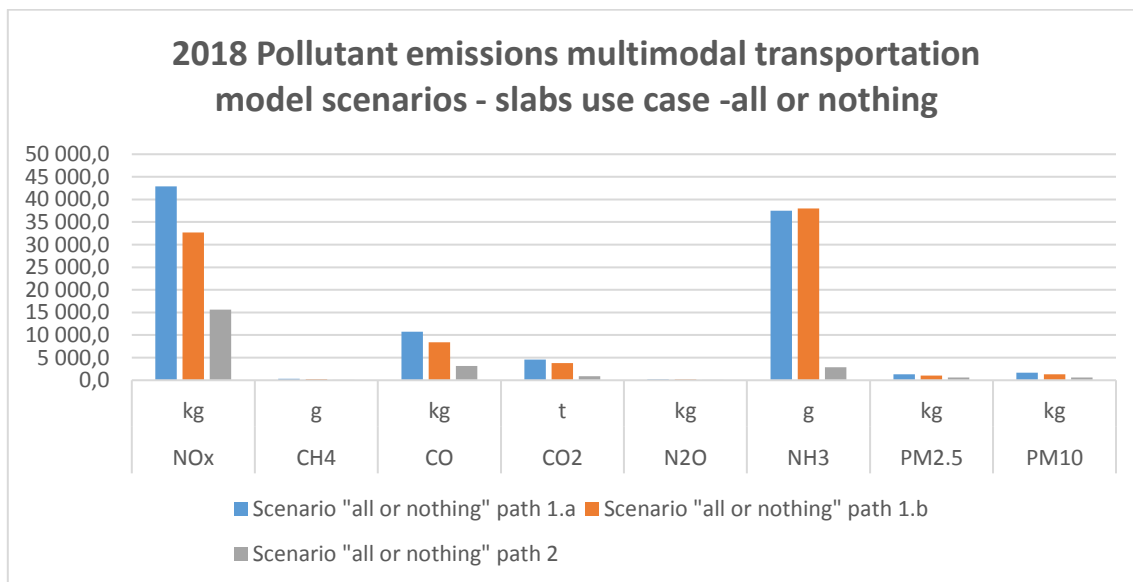


Figure 34: Pollutant emissions “all or nothing” scenario

The difficulty relates on the fact that the data are managed by third parties that are not partners in PIXEL project. So, in the following we are going to compare only trains and trucks mode of transport. In the next table pollutant emissions related to “fifty-fifty” scenario has been calculated:

Table 10: Pollutant emissions “fifty-fifty” scenario

2018 Poluttant emissions multimodal transportation model scenarios - slabs use case - fifty-fifty								
	NO <sub>x</sub>	CH <sub>4</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> O	NH <sub>3</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>
Year 2018	kg	g	kg	t	kg	g	kg	kg
Scenario "fifty-fifty" path 1.a	29 265,3	191,6	6 944,5	2 741,7	81,4	1 467,6	932,0	1 135,6
Scenario "fifty-fifty" path 1.b	24 172,8	147,9	5 760,2	2 376,1	78,7	1 467,9	794,6	955,0

In this case we have only 2 scenarios because we mixed trains and trucks tracks, so we lost only train scenario. As expected, these 2 scenarios stay in the middle between the worst scenario (only trucks to deliver slabs to industrial district) and the best scenario (only trains to deliver slabs to industrial district).



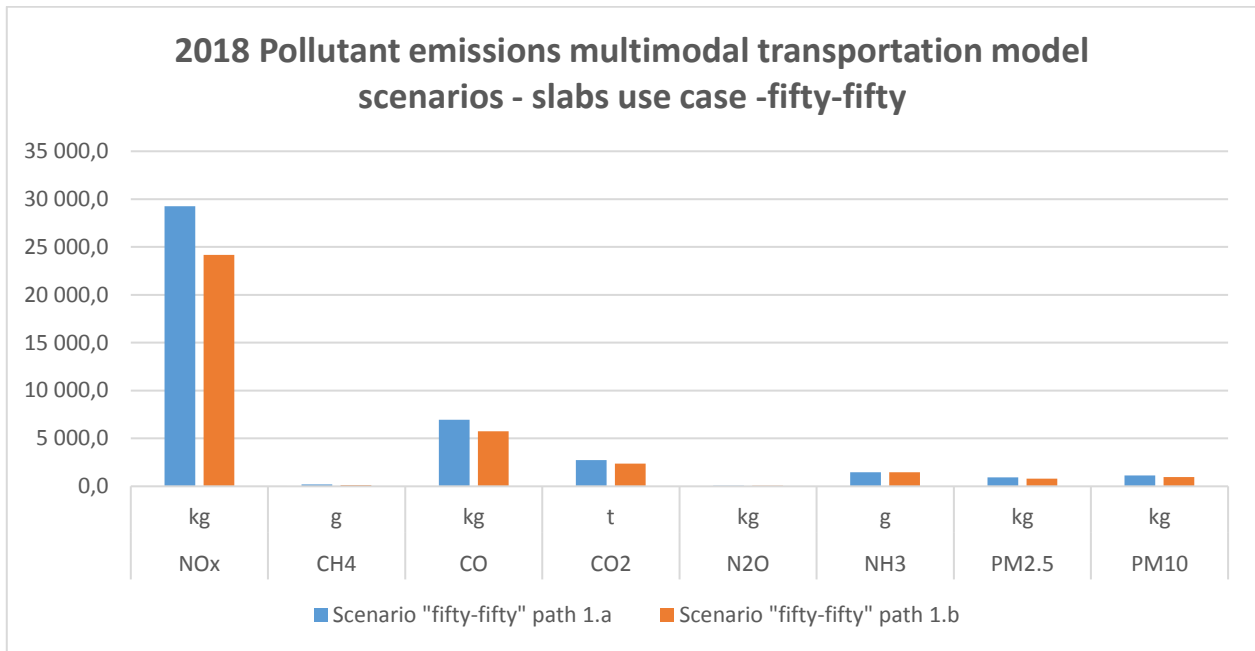


Figure 35: Pollutant emissions "fifty-fifty" scenario

The following figure compare performances, on pollutant emissions side, compared between all possible scenarios.

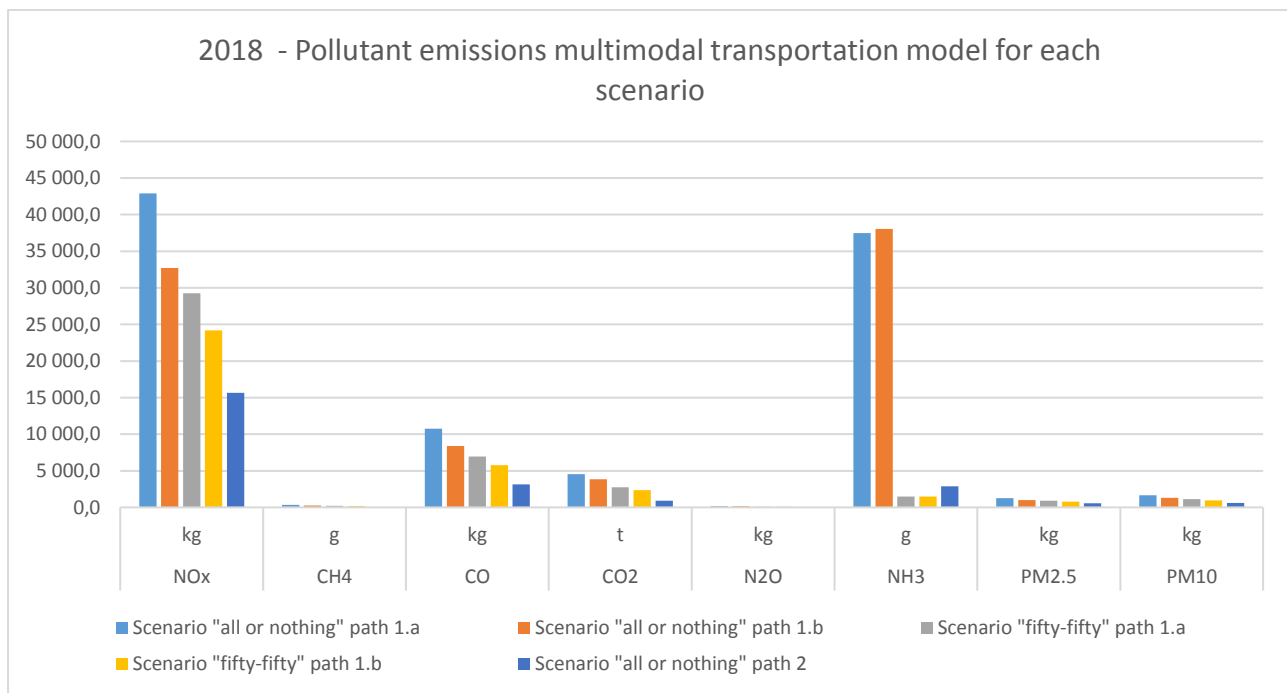


Figure 36: Pollutant emissions for all scenarios

Fixing scenario “all or nothing” path 1.a as the worst scenario (100 % of possible pollutant emissions) it is possible to directly see the performance of others scenarios defined in percentage. In this way it will be very easy identify what is the percentage of the reduction in pollutant emissions terms using multimodality.

Table 11: Pollutant emissions for each scenario in percentage against the worst scenario

	NO <sub>x</sub>	CH <sub>4</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> O	NH <sub>3</sub>	PM2.5	PM10
<b>Year 2018</b>	<b>kg</b>	<b>g</b>	<b>kg</b>	<b>t</b>	<b>kg</b>	<b>g</b>	<b>kg</b>	<b>kg</b>
<b>Scenario "all or nothing" path 1.a</b>	100%	100%	100%	100%	100%	100%	100%	100%
<b>Scenario "all or nothing" path 1.b</b>	76%	74%	78%	84%	97%	101%	79%	78%
<b>Scenario "fifty-fifty" path 1.a</b>	68%	58%	65%	60%	52%	4%	73%	68%
<b>Scenario "fifty-fifty" path 1.b</b>	56%	45%	54%	52%	51%	4%	62%	57%
<b>Scenario "all or nothing" path 2</b>	36%	15%	29%	20%	4%	8%	45%	37%

Then we can see, for example, as scenario “fifty-fifty” path 1.b reduce NO<sub>x</sub> pollutant emissions by 44% (100-56) and much more than this reduce NH<sub>3</sub> pollutant emissions by 96% (100-4).

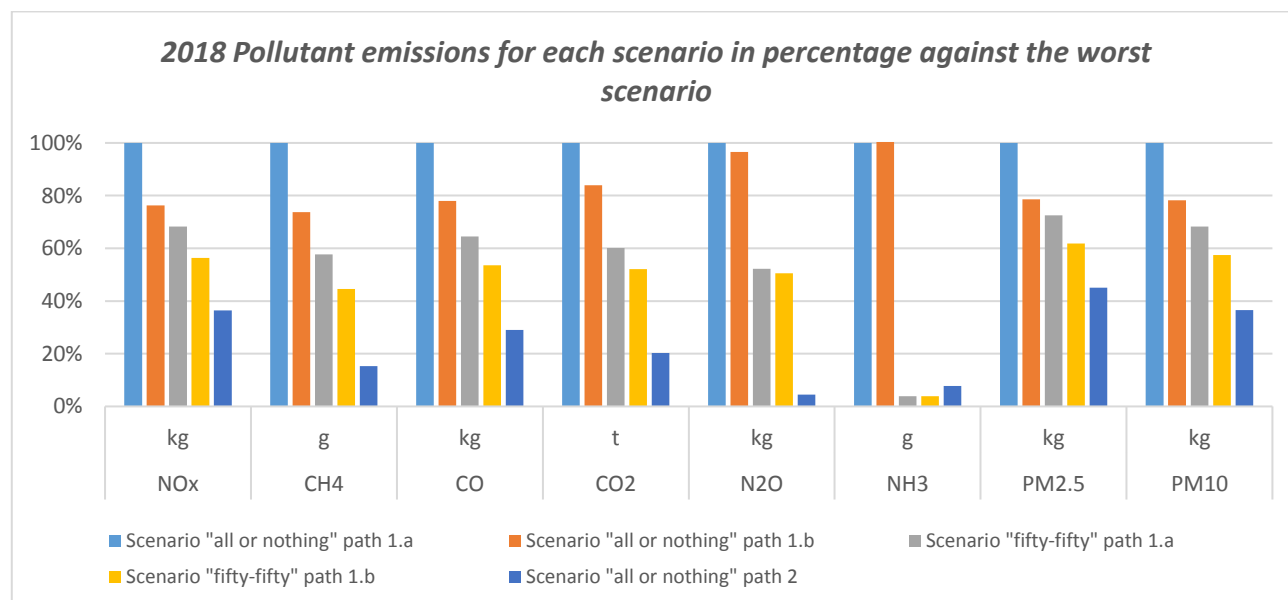


Figure 37: 2018 - Pollutant emissions for each scenario in percentage against the worst scenario

#### 5.3.3.1.4. Future trends

Tanks to Friuli Venezia Giulia funding, the company involved on trains transport was able to upgrade locomotors and railway carriages during 2019, it’s now possible to carry on 2.200 tons of slabs for each single train (instead of 500).

So a large number of transportation are spared and consequently train transportation become even more “environmental friendly” as shown below (considering the same amount of slabs delivered by trucks and by trains equal to 750.000 tons).

Table 12: 2019 Pollutant emissions “fifty-fifty” scenario

2019 Poluttant emissions multimodal transportation model scenarios - slabs use case - fifty-fifty								
	NO <sub>x</sub>	CH <sub>4</sub>	CO	CO <sub>2</sub>	N <sub>2</sub> O	NH <sub>3</sub>	PM2.5	PM10
<b>Year 2019</b>	<b>kg</b>	<b>g</b>	<b>kg</b>	<b>t</b>	<b>kg</b>	<b>g</b>	<b>kg</b>	<b>kg</b>
<b>Scenario "fifty-fifty" path 1.a</b>	23 114,9	171,5	5 689,6	2 285,0	78,6	328,6	704,2	896,4

<b>Scenario "fifty-fifty" path 1.b</b>	18 022,5	127,8	4 505,4	1 919,4	76,0	328,9	566,8	715,8
<b>Scenario "all or nothing" path 2</b>	3 346,8	10,9	619,8	10,9	1,5	619,8	124,0	130,2

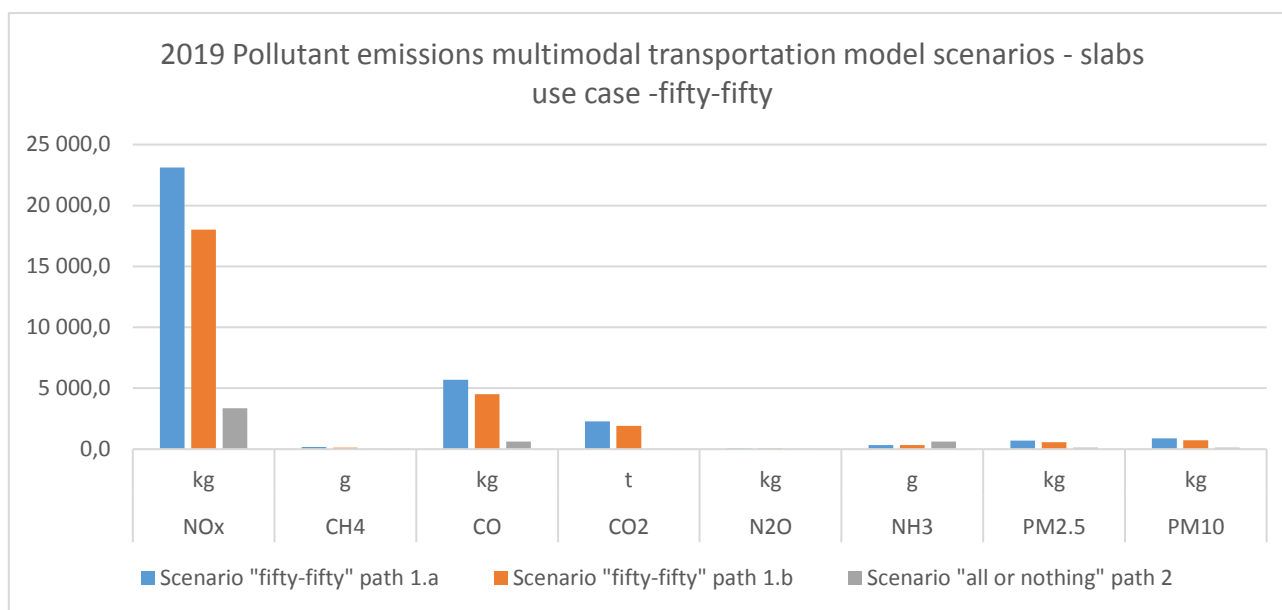


Figure 38: Pollutant emissions for all scenarios

Comparing 2019 figure against 2018 figure it is possible to note as scenario related only to train transportation mode (“all or nothing” path 2) is even less pollutant. This is also easier to see looking at the figure below, path 2 is almost not visible comparing to other paths.

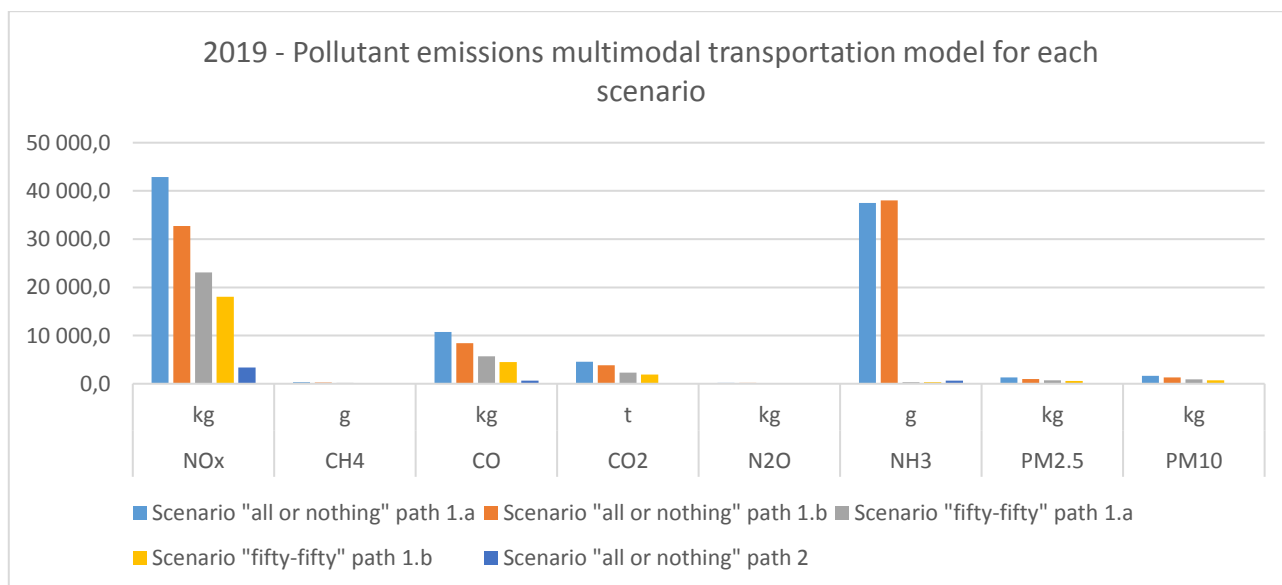


Figure 39: Pollutant emissions for all scenarios

The following table shows performances percentage of each scenario against worst scenario in 2019 transportation trend.

Table 13: 2019 Pollutant emissions for each scenario in percentage against the worst scenario

2019 Pollutant emissions multimodal transportation model scenarios - slabs use case - fifty-fifty								
	NOx	CH4	CO	CO2	N2O	NH3	PM2.5	PM10
Year 2019	kg	g	kg	t	kg	g	kg	kg
Scenario "all or nothing" path 1.a	100%	100%	100%	100%	100%	100%	100%	100%
Scenario "all or nothing" path 1.b	76%	74%	78%	84%	97%	101%	79%	78%
Scenario "fifty-fifty" path 1.a	54%	52%	53%	50%	50%	1%	55%	54%
Scenario "fifty-fifty" path 1.b	42%	38%	42%	42%	49%	1%	44%	43%
Scenario "all or nothing" path 2	8%	3%	6%	0%	1%	2%	10%	8%

So, with new upgrade to locomotors and railway carriages path 2 and path “fifty-fifty” increase their performances, from an environmental point of view, considerably.

For all possible emissions path 2 pollute less than 10% against worst scenario (and the others 2 scenario “fifty-fifty) pollute more or less a maximum of 50% against worst scenario); this is a great result for the whole community surrounding ASPM not only in relation to environmental issues, but also considering that using multimodality with a renew fleet take off from the street more than 2.000 trucks per year.

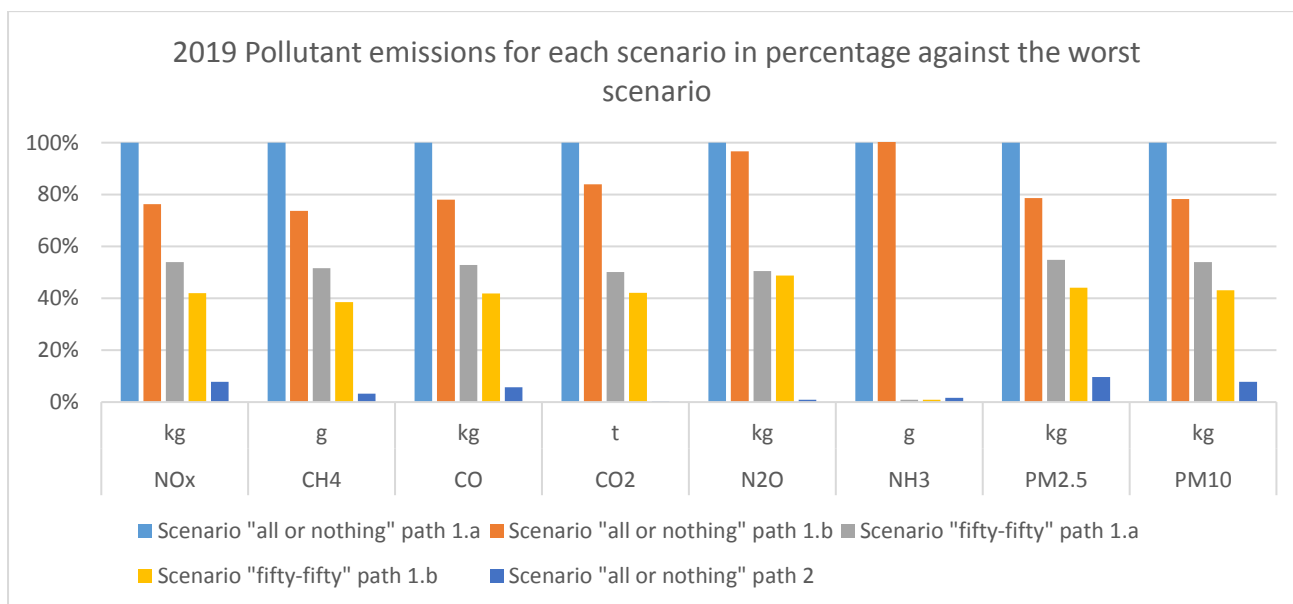


Figure 40: 2019 Pollutant emissions for each scenario in percentage against the worst scenario

### 5.3.3.2. Traffic sub model

To model congestion inside port area we need to understand how vessels through incoming and out coming activities influence trucks flow inside port area. In a nutshell, how many trucks are needed to move goods carried by vessels (we need to consider that Port of Monfalcone in mainly used for unloading operations).

Models will also consider the amount of trucks per hour entering and exiting port, and the parking lot occupancy provided by smart sensors and smart cameras, which will be installed as an outcome of the PIXEL project.

The proposed model is aimed at forecasting if a congestion will take place inside or outside the port (also involving the regional highway near the port, mainly used by trucks to reach and leave the port facility moving towards Italy, Austria and Slovenia). Such forecasting is influenced by both endogenous and exogenous factors, such as:

- Unloading and loading operations performed on arrived vessels: different operations can impact on the amount of trucks the port is able to host for interval of time;
- Weather situation;
- Road congestion;
- Traffic limitations due to Traffic Authority's order

These factors influence port access availability (input and output) and may trigger the diversion of incoming trucks from ASPM to SDAG in order to avoid congestion and reduce the amount of queued trucks waiting to access the port.

In order to perform forecasting the model requires different kind of input, provided by:

- Human operators and their expertise;
- Information Systems (SILI, PMIS);
- Sensors.

the models should be able to overlap different kind of data in order to extrapolate the amount of trucks which need a free slot on parking area. Data needed are depicted below:

- Planned arrivals and departures of vessels;
- Planned arrivals and departure of trucks;
- Real time parking occupancy;
- Real time situation on port's gates;
- External events which may impact on port truck rate.

To model how the vessel's loading and unloading activity influence trucks flow inside the port area and especially how this flow is related to lot parking demand we need to analyse historical data. In particular expertise provided by port's operators will allow us to evaluate, given an incoming vessel how the nature of the goods carried by the vessels (e.g.: bulk liquids, cars, etc.) can impact on the maximum number of trucks able to enter and leave the port each hour (**MaxFlow(h)**).

For example vessel A may reduce, according with its volume and goods, the amount of cargo which can be managed by the port by 15% until unloading operations are completed (**DeltaFlow(h, v)**).

Such information, like the average number of truck which can be loaded inside the port every hour, will be based on historical data provided by the port (**AvgFlow**).

According with the set of unloading activities involving one or more vessels, the model will forecast the capacity of the port to accept new trucks for a specific hour **h**. Such data is critical in order to prevent and incoming congestion.

$$\mathbf{MaxFlow(h)} = \mathbf{AvgFlow} * (100 - \sum_{\text{vessel } v} \mathbf{DeltaFlow(h, v)})/100$$

Exogenous factors can impact on **MaxFlow(h)** leading to:

$$\mathbf{RealMaxFlow(h)} = \mathbf{Max}(\mathbf{MaxFlow(h)} - \mathbf{ExternalDeltaFlow(h)}, 0)$$

For example  $ExternalDeltaFlow(h)$  may be estimated as  $\infty$  when local highway is closed because it's snowing.

In order to estimate the amount of trucks coming to the port for a given hour  $h$  and prevent congestions, several inputs will be used by the model:

- Trucks whose arrival is planned in SILI for  $h$  ( $Planned(h)$ );
- Average amount of planned trucks recognized by the port gates (in SILI) during previous 6 hours (as a ratio with respect to expected trucks) ( $AvgRealArrival(h)$ );
- Average amount of unplanned trucks recognized by the port gates (in SILI) during previous 6 hours ( $AvgUnplanned(h)$ );
- Real time parking occupancy and real time situation on port's gates provided by sensors ( $Parking(h)$ )

**ExpectedTrucks(h)**

$$= (Planned(h) * AvgRealArrival(h)) + AvgUnplanned(h) + 0,1 * Parking(h)$$

A queue (and the trigger event of a truck rerouting to SDAG), can be forecasted, for each hour, by analysing both RealMaxFlow and ExpectedTrucks.

$$Queue(h) = Max(0, Queue(h - 1) + ExpectedTrucks(h) - RealMaxFlow(h))$$

Planned arrivals and departure of both vessels and trucks give us an idea of near future parking slot demand. In the figure below two screenshots of the software to manage traffic sub model data are shown.

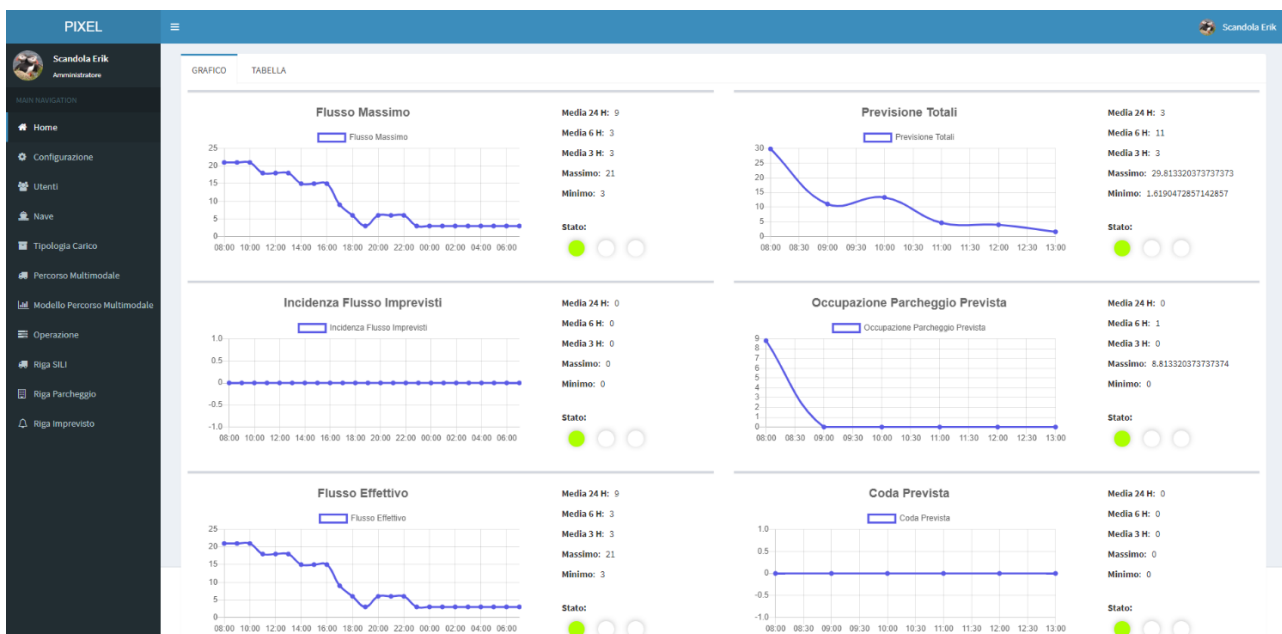


Figure 41: Dashboard of the software managing traffic sub model data (Italian version)

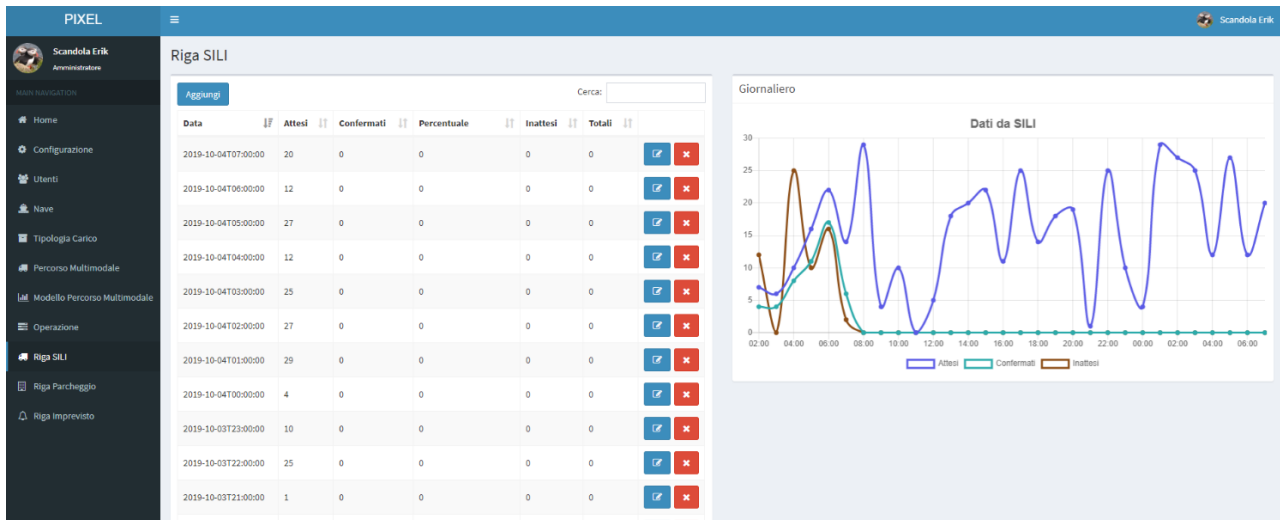


Figure 42: Dashboard of the software managing traffic sub model data – SILI data

Overlapping data explained above and applying predictive algorithms (tuned by analysing historical data) the model should be able to simulate trucks flow inside port area and forecast parking slots demand.

Combining this information with real time information about parking occupancy the model will be able to identify any critical situation eventually triggering diversion of incoming trucks from ASPM to SDAG.

The figure below shows traffic data provided by SILI system.

### 5.3.4. Requirements for integration of transport model in the PIXEL architecture

The requirements express in following section are referring to both submodel.

#### 5.3.4.1. Data requirements

The data requirements concerning the hinterland multimodal transport model are satisfied by the PIXEL platform by means of both DAL and Information Hub. In particular, the following data are required in order to properly feed the proposed model:

1. Data describing vessel arrival and transported goods (in terms of both weight and description of the specific stuff that will be downloaded at the port), coming from the PMIS information system and available (at least on a daily basis) on the Information Hub by means of a specific DAL agent;
2. Data describing truck arrival (expected and unexpected) coming from the SILI information system and available (at least on a daily basis) on the Information Hub by means of a specific DAL agent;
3. Historical data provided by both SDAG and Port of Monfalcone concerning average pollution and energy consumption of each different transportation mode used to move slabs (or more generally stuff) from the port to their destination in the hinterland areas;

Data acquired by a set of smart cameras installed inside the roof of the administrative area of the port, pointed on the parking area truck usually use as a buffer when port entrance is not available or when a traffic congestion is happening.

### 5.3.4.2. System Requirements

The model will be written in .NET Core and will not require any particular computational resource. A VM with standard capabilities (e.g.: 4 GB of RAM, 2 VCPU) will supply the required resources. The software will run on both Linux and Windows operating system.

### 5.3.4.3. Visualization, triggers and KPIs

The model will be usable in web interface, embedded within the PIXEL visualization framework, and allow to show to the users (Monfalcone Port, SDAG and other Regional Stakeholders) how is the situation in real time and in the next future, based on data collected in the Information Hub. The visualization is based on table and a rich set of charts, in order to be easily understandable by the users.

According with the incoming traffic (defined in terms of both vessels and truck) and the parking lot availability measured in real time by the smart cameras, the model is able to predict if a queue will take place and the critical time slot. Through a set of charts, the model provides operators of the port with an eagle eye view of the next 24 hours, by providing inside a common dashboard a comprehensive representation of the status of the port traffic.

For each defined transportation mode, according with its particular pollutants and energy demands, a comparison chart is used to make differences clear and easy to understand

When the model predicts that a queue will or may reasonably appear in the next few hours, a set of triggers may be fired in order to prevent new truck to reach the port, by suggesting them to wait in SDAG (if parking is available), in order to both reduce congestion and avoid truck drivers to wait on the streets outside the port for a long time without any support service. The triggers will be created within the model, but their visualization and notification will be managed within PIXEL framework by dashboard and notification module (WP6 with feedbacks of WP7).

### 5.3.4.4. Training requirements

Considering that all PIXEL infrastructure will be hosted in the Insiel Data-Center, the training requirements is only related to the working-station in the Port of Monfalcone and in SDAG. Both them must have a personal computer and internet connection to access to PIXEL and use the operational tools available in PIXEL.

### 5.3.4.5. Transferability requirements

The model proposed in order to deal with hinterland multimodal transportation could be proficiently transferred to several other ports for several reasons:

1. Data required by the model (ship call, port's gates entrances) are common to all ports and already stored for both legal and operational reasons;
2. Computation is fast and can describe in almost real time system evolution over time according with new inputs;
3. Code is open and based on open source standards.



## 6. Environmental Pollution Models

### 6.1. Introduction and scope

Based on the user stories the modelling tools will be applied in order to predict the impact of emissions sources on the environment. We will address modelling at local or possibly regional scales (up to 100 km in diameter) but the global behaviour of pollutants will not be addressed, and it is beyond the scope of this modelling exercise. Actually, the needs of the ports are more focused on the macroscopic effect to understand to which area of the city the pollutants will be impacted rather than on a fine understanding of the reactions and interactions between pollutants. We are well aware that not taking into account the reactive phenomena will distance us from the reality and this choice constitute a limit of the models set up. However, using this approach for PIXEL models will be easier to implement and better meet the needs of ports.

Air pollution is one of the main concerns expressed by ports in the PIXEL project. Indeed, many sources of emission (often mobile sources) are present in the ports and reject pollutants including particles matter, oxides nitrogen, oxides sulphide, monoxide of carbon, etc. Regarding dispersion in the atmosphere and the type of pollutants, for now it seems that particulate matter (PM) is the most important pollutant that ports want to address. The second point of interested of ports is relating with noise pollution.

Thus, because PIXEL is use-case centric, we will initially focus on setting up models on these two themes. However, we are well aware that emissions into water and soil are also important and that their modelling could also help ports reduce their environmental impacts. Nonetheless it is worth noticing that dispersion models of pollutants in water and soil require input data which are not currently available in ports and which would require substantial investment. Moreover, the dispersion models in water and soil can quickly become too complex to obtain a satisfactory accuracy and would require a time of implementation which would not allow us to treat properly the elements put forward by the ports.

### 6.2. Available data

#### Emissions to atmosphere

The data required for modelling pollution dispersion are mainly meteorological data coupled with data on emissions from sources inside the port.

- Emission data which will be obtained under PIXEL will be derived from proxy data (eg. energy consumption) and will thus be less accurate than data obtained from direct measurements.
- Data which will be obtained from direct measurements include some of the meteorological data such as wind speed.

#### Noise emissions

The data needed to noise mapping are:

- For noise level estimations there are direct measurements available made by the ports.
- Geographical information:
  - Spot heights and contours
  - Residential and industrial buildings
  - Other obstacles in the study area (e.g. containers' formations)
  - Location of noise sources
  - Location of noise sensitive areas
  - Identification of surface characteristics of ground
- Industrial noise sources:
  - Location of every relevant industrial source (cargo handling, container handling, cranes, vehicles, auxiliary equipment) including height.

- Working hours of every source considered for day, evening and night period.
- Sound power level of each industrial source.

The source provider of all the input data (both proxy and directly measured data) is the port. For other data such as dispersion coefficient, emission factors, etc. data will be derived from the Port Activity Scenario or literature. For certain parameters historical data sets exists, such as meteorological data and noise measurements. But for other parameters such as data on emissions or even proxy data on energy consumption could be lacking.

### 6.3. Modelling of air pollution

The objective of the air pollution is to creating a tool for small and medium ports to estimate the air pollution emitted by a port using validated technologies. Based on existing measurements and port activity data, the model should simulate the air pollutant dispersion caused by various activities and operations taking place within the port. By using historical data, it will simulate the current state of the ambient air in the port and with help of weather predictions models, it should be able to simulate the possible future air quality situation. These simulations can assist the port manager/operator in the decision-making process in order to optimize various activities within the port and minimize their impact on the environment.

#### 6.3.1.1. Description of the model

An air dispersion modelling attempt was using the American Meteorological Society (AMS) and the United States Environmental Protection Agency (EPA) Regulatory Model – AERMOD. It is a steady-state Gaussian plume air dispersion model which predicts downwind pollutant concentrations based on source emissions, site parameters (terrain features, land use, etc.), meteorological fields, building locations and more

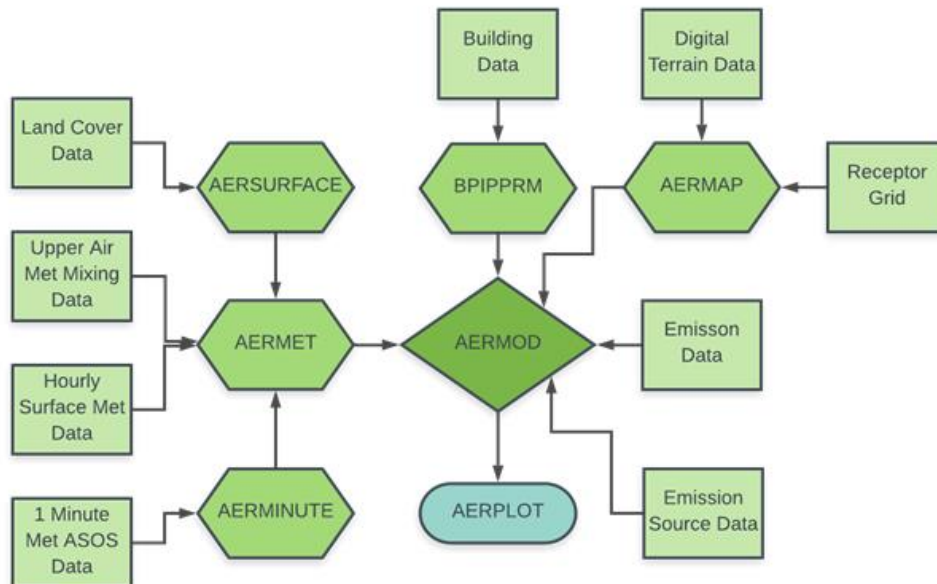


Figure 43: Workflow for the use of AERMOD

The AERMOD modelling system includes five pre-processors, one main dispersion model and one post processors. The pre-processors are:

- 1) AERMET - a meteorological data pre-processor that that processes commercially available meteorological data.
- 2) AERMAP - a terrain data pre-processor that processes custom on-site or commercially available digital elevation data.

- 3) AERSURFACE
- 4) AERMINUTE
- 5) BPIPPRM

The main dispersion model is AERMOD and the post processors is AERPLOT. Figure 44 depicts the relation between all the different models and minimum data needed for a successful simulation run of the AERMOD Modelling system.

Regarding AERMOD's implementation in the PIXEL platform only AERMET, AERMAP, AERMOD and AERPLOT models have been used. The other components from the AERMOD Modelling System were discarded for several reasons. Namely, to make it more user friendly and because of limited data availability. Also, the post processing and visualization will most likely be done without the help of the AERPLOT post processor. All the needed documentation and executables were obtained for the US Environmental Protection Agency's website free of charge. A short description of each used model can be found below (U.S EPA, 2019)<sup>3</sup>.

### **AERMET**

It is a meteorological data pre-processor split in three different stages and each stage has its own input file. AERMET processes commercially available meteorological data or site-specific meteorological data. Input data are

- Upper Air Mixing data<sup>4</sup>,
- Hourly surface data<sup>5</sup>.

### **AERMAP**

This is the terrain pre-processor for AERMOD. It determines the hill height scale and elevations for each receptor and pollution source based on the digital terrain data. Input data are:

- Digital terrain data,
- Receptor and source data.

### **AERMOD**

Is the US Environmental Protection Agency's preferred dispersion model for regulatory modeling application. AERMOD is used for the determination of shortrange (up to 50 km) impacts from various emission source in all types of terrain. Input data are

- Emission source information and location,
- AERMAP output file,
- AERMET output file.

### **AERPLOT**

Creates contour plots and color-coded receptor locations based on the AERMOD output file and visualizes them in Google Earth Pro. Input data are:

- AERMOD output file.

#### **6.3.1.2. Limitations and assumptions**

Given that the AERMOD Modelling System is the most tested and preferred state-of-the-art dispersion modelling system recommended by the U Environmental Protection Agency it provides reliable results. To get

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<sup>3</sup> <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models>

<sup>4</sup> Available at: <ftp://ftp.ncdc.noaa.gov/pub/data/noaa>

<sup>5</sup> Available at: <ftp://ftp.ncdc.noaa.gov/pub/data/igra> or: <https://ruc.noaa.gov/raobs/>

those results a lot of data is needed, and the model usage is not very user friendly. To overcome these obstacles two different approaches were suggested and discussed, which will be further elaborated in the next section: Also, ignoring the building downwash effect can have impact on the results reliability.

### 6.3.2. How the model works

Two different approaches have been discussed for addressing air pollution:

- 1) Using AERMOD (and the output it provides) for the modelling of air pollution.
- 2) Using a "meta-program" inspired by AERMOD but lighter and with the ability to create a similar output based on changing values instead of consolidated steady-state inputs.

The MEDRI team had a discussion with the Faculty of Engineering in Rijeka about the best methodology to achieve the desired results. The metamodel idea was discarded because of several reasons:

- 1) a large enough data would be needed to get a reliable output for a meta function (and we already have problems obtaining the bare minimum of data);
- 2) the metamodel results wouldn't be as reliable as AERMOD results;
- 3) and one of the biggest issues is that the model wouldn't be generic. For each port, a separate metamodel would be needed.

It was concluded that the best way to do this is to write scripts which essentially are "shells" for the open source pollution modelling software AERMOD. The scripts performs as follows:

- Prepares the needed input data
  - The user will be able to manually decide where the source locations are and what type they are (point, area, line volume, etc.). This way we fulfil the requirement of a generic model. The other option is that the source location is decided before (during the model's initialization) and the user can "turn on and off them" before running a new simulation.
  - The model should have some fixed parameters to make it more user-friendly and easier to execute.
  - The user needs to fill in emission data, which depends on the source type (mainly emission velocity, temperature, if it is a point source stack diameter)
  - Possibly uses weather forecasts models for simulating future possible scenarios<sup>6</sup>.
- Launches the.exe files
- Then pulls the output files. Analyse and visualize them in Google Earth.

To summarize, the scripts generate input files by "filling the gaps" in a predefined text file with the information given by a user. The completed input files then can be used for running the different executables. In this following, the idea and mechanics behind the python scripts are shown. To make it easier to understand and use these scripts everything will be explained through the example of the port of Thessaloniki<sup>7</sup>.

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<sup>6</sup> <http://www2.mmm.ucar.edu/wrf/users/download/>

<sup>7</sup> Words of caution. All Emission source parameters were completely made up and serve only to demonstrate how the scripts work. Data used for this case are weather data for the year 2018 (WMO ID: 16622), 11 point sources, 13 line source, 1 area source and 1 volume source. Additional two receptor grids were generated layered one over another, which can be useful for getting more accurate results in a critical area.

### 6.3.2.1. AERMET

It is a meteorological data pre-processor split in three different stages and each stage has its own input file. AERMET processes commercially available meteorological data or site-specific meteorological data. The needed meteorological data are freely available from The National Centers for Environmental Information's website. Needed input data are:

- Hourly surface data – measured somewhere between the ground level and 10m – at the earth's surface. Physical parameters measured: temperature, wind direction, current weather, dew point, visibility, wind speed, cloud layer(s), cloud cover, ceiling height, and precipitation amount. Surface data are for each hour. To find the data needed the 5 - digit World Meteorological Organisation (WMO) ID of the nearest weather station has to be known (Example: for the Port Of Thessaloniki the WMO ID is 16622)<sup>8</sup>.
- Upper Air Mixing data - measured in the vertical layers of the atmosphere. usually measured by radiosonde soundings twice daily, 00 and 12 h (Greenwich time). To obtain the data there are more options on how to find it<sup>9</sup>:
  - 5 - digit World Meteorological Organisation (WMO) ID
  - Country
  - Latitude and Longitude

As mentioned before the AERMET model processes the data through 3 stages. So, the script produces 3 separate input files which have to be run one after another in specific order (First stage1.inp, followed by stage2.inp and lastly the stage3.in must be run). The script asks the following input (U.S EPA, AERMET User guide)<sup>10</sup>:

- Enter Title
- Enter Upper air mixing data input file name, path and type
- Observation period
- Station's latitude and longitude (where the upper air data was collected)
- Time Offset from Greenwich [h]
- Enter Hourly Surface data input file name, path and type
- Station's latitude and longitude (where the hourly surface data was collected )
- Station elevation [m]
- Wind measured at height [m]
- Specify period and sectors (need for the calculation of some boundary layer parameters)
- The midday albedo
- Daytime Bowen ratio
- Surface roughness length [m]

<sup>8</sup> Available at: <ftp://ftp.ncdc.noaa.gov/pub/data/noaa>

<sup>9</sup> Available at: <ftp://ftp.ncdc.noaa.gov/pub/data/igra> or: <https://ruc.noaa.gov/raobs/>

<sup>10</sup>

[https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKewjnzoCkupzIAhVOBWBHhALsAZMQFjAAegQIABAC&url=https%3A%2F%2Fwww3.epa.gov%2Fftn%2Fscram%2F7thconf%2Faermod%2Faermet\\_userguide.pdf&usg=AOvVaw3SUn\\_39Zhku1lmJrAAzKpc](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKewjnzoCkupzIAhVOBWBHhALsAZMQFjAAegQIABAC&url=https%3A%2F%2Fwww3.epa.gov%2Fftn%2Fscram%2F7thconf%2Faermod%2Faermet_userguide.pdf&usg=AOvVaw3SUn_39Zhku1lmJrAAzKpc)

After the user successfully enters all the needed information the script produces the following 3 input files.

```

JOB
  REPORT  AllOutputs\THESSAERMET.RP1
  MESSAGES AllOutputs\THESSAERMET.MG1

UPPERAIR
  DATA  data\thessaloniki2018AU.txt FSL
  EXTRACT AllOutputs\THESSAERMET.UAX
  QAOUT  AllOutputs\THESSAERMET.UQA

  XDATES  2018/01/01 TO 2018/12/31

  LOCATION 99999 40.520N 22.970E -2

SURFACE
  DATA  data\thessaloniki2018SF ISHD
  EXTRACT AllOutputs\THESSAERMET.SAX
  QAOUT  AllOutputs\THESSAERMET.SQA

  XDATES  2018/01/01 TO 2018/12/31

  LOCATION 99999 40.533N 22.967E -2 7.00
    
```

Figure 44: AERMET script's result 1

The first stage extracts and quality assure the standard hourly surface data and the upper air mixing data.

```

JOB
  REPORT  AllOutputs\THESSAERMET.RP2
  MESSAGES AllOutputs\THESSAERMET.MG2

UPPERAIR
  QAOUT  AllOutputs\THESSAERMET.UQA

SURFACE
  QAOUT  AllOutputs\THESSAERMET.SQA

MERGE
  OUTPUT  AllOutputs\THESSAERMET.MRG

  XDATES  2018/01/01 TO 2018/12/31
    
```

Figure 45: AERMET script's result 2

The second stage merges the upper air and surface data into a single file.

```

JOB
  REPORT  AllOutputs\THESSAERMET.RP3
  MESSAGES AllOutputs\THESSAERMET.MG3

METPREP
  DATA  AllOutputs\THESSAERMET.MRG
  MODEL  AERMOD

  OUTPUT AermodInputs\THESSAERMET.SFC
  PROFILE AermodInputs\THESSAERMET.PFL

  XDATES  2018/01/01 TO 2018/12/31

  METHOD  REFLEVEL SUBNWS
  METHOD  WIND_DIR  RANDOM
  NWS_HGT WIND      10

  FREQ_SECT ANNUAL 2
  SECTOR    1 90 270

  SECTOR    2 270 90

  SITE_CHAR 1 1 0.2075 1.6250 1.00000
  SITE_CHAR 1 2 0.1400 0.4500 0.00010
    
```

Figure 46: AERMET script's result 3

The last stage processes the meteorological data and generates the profile and surface meteorological data files needed as an input for AERMOD. After the scripts successfully generates the needed input files, the AERMET

executable can be run via command prompt using these three input files. AERMET generated files THESSAERMET.SFC and THESSAERMET.PFL shown in the figure above are used as inputs for the AERMOD model.

### 6.3.2.2. AERMAP

The second pre-processor used for the air dispersion modelling task is the AERMAP terrain pre-processor. This one is important for connecting the terrain elevation of the studied area with the receptor and sources locations. This script also generates two help files which will be automatically inserted in the AERMOD input file. By running the script, the user is asked the following input (U.S EPA, AERMAP User guide):

- Enter Title
- Enter Domain UTM (Universal Transverse Mercator) coordinates and dimensions
- Enter Domain UTM Zone
- Source type
- Number of sources of given source type
- Source UTM coordinates and dimensions (for all sources types)
- Pollutant Emission rate [g/s] (for all sources types)
- Stack height [m] (for point and line sources types)
- Stack temperature [K] (for point source)
- Stack velocity [m/s] (for point source)
- Stack diameter [m] (for point source)
- Line width [m] (for line source)
- Number of receptors

After the user successfully enters all the needed information the script produces the following input file which then can be used for running the AERMAP executable.

```

CO STARTING
TITLEONE THESS
TERRHGT5 EXTRACT
DATATYPE DEM FILLGAPS
DATAFILE "data//N40E022.dem"
ANCHORXY 0.0 0.0 0.0 0.0 34 3
RUNRNOT RUN
CO FINISHED

SO STARTING
LOCATION STCK1 POINT 661950.000 4500394.000 0.0
LOCATION STCK2 POINT 661961.000 4500390.000 0.0
LOCATION STCK3 POINT 661998.000 4500326.000 0.0
LOCATION STCK4 POINT 662021.000 4500269.000 0.0
LOCATION STCK5 POINT 662028.000 4500248.000 0.0
LOCATION STCK6 POINT 662087.000 4500094.000 0.0
LOCATION STCK7 POINT 662098.000 4500065.000 0.0
LOCATION STCK8 POINT 662261.000 4499986.000 0.0
LOCATION STCK9 POINT 662274.000 4500002.000 0.0
LOCATION STCK10 POINT 662244.000 4500090.000 0.0
LOCATION STCK11 POINT 662183.000 4500252.000 0.0
LOCATION VOL1 VOLUME 661042.730 4500821.780 0.0
LOCATION PAREA1 AREAPOLY 662694.02 4500492.05 0.0
SO FINISHED

RE STARTING
GRIDCART UCART1 STA
XYINC 660192.0 21 200.0 4498885.0 21 150.0
GRIDCART UCART1 END
GRIDCART UCART2 STA
XYINC 661595.12 21 40.00 4500261.00 21 35.00
GRIDCART UCART2 END
RE FINISHED

OU STARTING
RECEPTOR AermodInputs\THESSAERMAP.ROU
SOURCLOC AermodInputs\THESSAERMAP.SOU
OU FINISHED

```

Figure 47: AERMAP script's result

The generated files THESSAERMAP.ROU and THESSAERMAP.ROU are used as an input for the AERMOD model.

### 6.3.2.3. AERMOD

This is the main model and all the outputs generated with the previous scripts are used in the input file needed for the AERMOD simulation run. As almost everything is prepared before this script asks the user only the following input (U.S EPA, AERMOD User guide):

- Needed input
- Enter Title
- Enter Pollutant's name
- Enter base elevation [m]

Which generates the following input file.

### 6.3.2.4. AERPLOT

After a successful AERMOD simulation run. Using the .PLT files the results can be visualised with the help of AERPLOT and Google Earth Pro:



Figure 48: Example of results for the air dispersion model

The figure above shows results from the Port of Thessaloniki example. The receptor colouring represents the concentration of SO<sub>2</sub> and the red shapes stand for the different source types.



### 6.3.3. Requirements for integration of air pollution model in the PIXEL architecture

#### 6.3.3.1. Data requirements

The data needed for a successful model run is already mentioned in the sections above. To summarize, the needed data can be divided in two sections. One which is available online (weather and surface data) and data which can be provided by the port (port specific data, source location and other information).

#### 6.3.3.2. System Requirements

The script for the AERMOD Modelling system is written in Python so regarding that the system requirement is relatively low. As for the model(s) itself, it was developed within the Microsoft Windows operating system and it is designed to be run using command line arguments. The needed storage space on the hard disk is heavily depended on the running and output options selected for the run. The main requirements are an Intel 4 processor or higher, 2 GB of Ram and minimum of 2 GB available hard disk space.

#### 6.3.3.3. Visualization, triggers and KPIs

The model will be used via the interface which is encapsulated within the global PIXEL visualisation framework. Most of the data will be automatically collected which will be done in WP6. As shown in section 6.3.2.4 the results can be visualised with the help of the AERPLOT postprocessor model in Google maps with contour maps and colour coordinated receptors. Such visualisation is easily understood by the end user and he can conclude where the highest contraptions of a certain pollutant are.

If the model concludes higher than normal concentration of a pollutant a set of trigger can be fired in order to modify or postpone an operation causing the high level concentrations. This also will be done within the work packages 6 and 7.

#### 6.3.3.4. Training requirements

The model does need minimum training for the users. So, they can understand how it works, which input is needed and how to interpret the output contour maps and files.

#### 6.3.3.5. Transferability requirements

The models as it is can be deployed at any port without any problems. The only static parameters are the surface data and the UTM coordinates. Other data like weather and source information will be given directly by the user (or automatically collated) in each port.

## 6.4. Modelling of noise dispersion

As stated in the works such as (Hadzi-Nikolova, 2013), noise pollution represents both a threat to human health and lowers the quality of life in areas affected by it. In order to reduce the impact of the noise, noise dispersion models can be used. With the help of those models, it is possible to assess the noise levels in various areas and, consequently, decide which ones of them are in the most critical situation. It is important to note that it is not enough to use only one noise level in that decisions. Various types of areas have different allowed noise levels, based on its purpose. A general list of zones with their permitted noise emissions is given in Table 14, purely

as orientational values, as those levels might be different, based on the law or even on the special regulations for the specific port area (Kovačević, 2013). In the following, the modelling approach is detailed using port of Thessaloniki as an example.

*Table 14: Permitted noise emissions by zone (Kovačević, 2013)*

Noise zone	The purpose of the site	Maximum permitted noise emissions LRA <sub>eq</sub> dB(A)	
		day	night
1	The zone is intended for rest, recovery and treatment	55	40
2	The zone is intended for housing and residence	55	40
3	Mixed-use zone, predominantly residential	55	45
4	Mixed-use zone, mainly business	65	50
5	Zone for commercial purpose (production, storage, service, etc.)	80	80

Considering the “modelling needs” stated by the ThPA personnel, which can be read in the Appendix B1.4, noise pollution is one of the significant issues. Most of the opinions stated the need to assess the influence that the port has on the total pollution levels in the city. The assessment of noise influences the port has on its environment can be done using the previously mentioned noise dispersion models (noise maps). Using the noise maps, the port can evaluate its environmental performance in that aspect and also identify the most critical areas. It is especially useful in placing noise sensors, as they should be placed in the areas with the highest level of noise pollution. In addition, if there is an overshoot of the regulated noise levels, the port can use different scenarios when trying to reduce those levels. Testing of those scenarios is enabled with the use of noise maps.

### 6.4.1. Description of the model

The primary goal of the noise modelling is to have a model that is reliable for use by the ports and which supports most, if not all, of their modelling requirements. Using noise dispersion models, those objectives can be achieved by calculating noise levels in various points across the port area, or around it, and also by setting a number of points in which are the simulated noise levels compared with those regulated by the law.

Calculation of those noise levels depends on the calculation method that is used, which in turn depends on the calculation methods supported by the software used and the requirement needs. Also, not all calculation methods are intended for the modelling of all noise sources. Based on that criteria, they can be divided into four main categories:

- Methods that can be used for the modelling of all noise sources;
- Methods that can be used only for the modelling of industrial sources;
- Methods intended for the modelling of road noise;
- Methods intended for the modelling of railway noise.

In PIXEL noise dispersion model was done using Predictor-LimA Software Suite, developed by Brüel & Kjær. The decision of using this software has been reasoned in Appendix C. According to the developer, the main uses for the program are the following<sup>11</sup>:

- Environmental noise prediction – for industrial sources, traffic sources (road, rail and air traffic) and wind turbines
- Noise mapping
- Noise management

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[https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjo2uXfupzIAhUaBGMBHcBUAFUQFjAAegQIBBAC&url=https%3A%2F%2Fwww.softnoise.com%2Fdownload%2FProduct\\_Data-Predictor-LimA-V2019.pdf&usg=AOvVaw0vMAO-ZSQF\\_Idwo97GVSOy](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjo2uXfupzIAhUaBGMBHcBUAFUQFjAAegQIBBAC&url=https%3A%2F%2Fwww.softnoise.com%2Fdownload%2FProduct_Data-Predictor-LimA-V2019.pdf&usg=AOvVaw0vMAO-ZSQF_Idwo97GVSOy)

- Action planning
- Impact assessment

The software suite consists of three software combined into one software package:

- Predictor – software intended for environmental noise prediction and noise mapping, which supports 20 calculation standards. It is considered to be more intuitive than LimA.
- LimA - it is also intended for use in environmental noise prediction and noise mapping. It supports more standards than Predictor (30) and is mainly used when calculation standards not supported by Predictor are required.
- Acoustic Determinator – used for the sound power levels determination in accordance with several different measurement methods

In order to start with the noise mapping, several different data inputs are required. The data inputs were described during the course of the NoMEPorts project<sup>12</sup>, described in more detail in the Appendix B4.3, and consists of the following required data:

- Geographical data
- Data about noise sources
- Meteorological data

The geographical data should contain:

- Spot heights and contours
- Residential and industrial buildings (including height dimensions)
- Other obstacles, like containers' formations, noise barriers etc.
- Locations of noise sources, both industrial and traffic sources
- Locations of noise sensitive areas, such as schools or hospitals
- Identification of surface characteristics of ground

After the geographical data is obtained, there is a requirement for the data on the noise sources. The noise sources can be divided in two categories:

- Industrial noise sources
- Traffic noise sources

The sources of traffic noise include, but are not limited to:

- Roads
- Railways
- Ships (moving)
- Air traffic

## 6.4.2. Limitations and assumptions

Several assumptions and/or simplifications must be made before the model can be created. Considering the noise sources described in the previous subchapter, the railway and road traffic were kept intact, with the average

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[https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjUtLaFu5zIAhV6A2MBHYTUBgYQFjAAegQIABAC&url=http%3A%2F%2Fec.europa.eu%2Fenvironment%2Flife%2Fproject%2FProjects%2Findex.cfm%3Ffuseaction%3Dhome.showFile%26rep%3Dfile%26fil%3DLIFE05\\_ENV\\_NL\\_000018\\_LAYMAN.pdf&usg=AOvVaw1L-jRdNL66xOzJRqSaZMcL](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjUtLaFu5zIAhV6A2MBHYTUBgYQFjAAegQIABAC&url=http%3A%2F%2Fec.europa.eu%2Fenvironment%2Flife%2Fproject%2FProjects%2Findex.cfm%3Ffuseaction%3Dhome.showFile%26rep%3Dfile%26fil%3DLIFE05_ENV_NL_000018_LAYMAN.pdf&usg=AOvVaw1L-jRdNL66xOzJRqSaZMcL)

hourly traffic during the day serving as an input data (although using different calculation models, as will be described later). However, even in that case, there were several assumptions made:

- Many of the “roads” are not roads in the classical sense of the word, but paved areas on which transport trucks drive. The “roads” were positioned in the middle of those surfaces.
- Also, some roads end on a parking slot and it is always a matter of personal judgement where the end of the road would be placed. In this case, they were placed approximately in the middle of those parking areas.

As for the other traffic data, there is no air traffic in the port area, while the vessels are included as a part of the industrial noise (berthed vessels).

There are also some other simplifications introduced. Although the height data was provided by the port authorities, the influence of it on the results was very small (most of the port has a height in range of one meter), so it would be left out when showing noise maps, for sake of clarity of the map and the shorter calculation time. The comparison of the result with and without the height data can be seen in the Table 15.

*Table 15: Comparison of the results with and without height points*

Receiver	Lnight (dB(A))			LDEN (dB(A))		
	With HP	Without HP	Difference	With HP	Without HP	Difference
1	53.1	53.1	0	59.5	59.5	0
2	42.1	42.1	0	54.6	55.7	1.1
3	42	41.7	-0.3	56.7	56.6	-0.1
4	40.3	39.5	-0.8	49.6	49.8	0.2
5	43.7	43.7	0	53.7	53.9	0.2
6	45	44.9	-0.1	55.4	55.6	0.2
7	47.3	47.3	0	59.5	59.6	0.1
8	49.2	49.2	0	61.6	61.7	0.1
9	43.8	43.8	0	59	59.2	0.2
10	41.2	41.3	0.1	55.7	57.3	1.6

Some other simplifications were made before, in the data provided by the port. For example, there are several areas in which various machinery constantly operates. It would be extremely complicated to model each of them as a line or a point source, so those areas were modelled as area sources. However, by using the Port Activity Scenario, it will be possible to have an average estimation of noise for each machinery.

Most of the other data is used without any simplifications and assumptions, except for a couple of things concerning the buildings data. The data about height buildings was provided by the ports. There were heights assumed only for few tanks and prefabricated buildings, but it doesn't have any direct influence on the results. The assumption was done by checking images and comparing those buildings with the buildings that have height values. Considering the buildings, there is also an assumption considering reflection factors for buildings, with the default values being used.

There is also another issue that should be addressed and that is the technical limitation of the noise modelling software. The only real technical limitation, not counting possible hardware problems, is the maximal model size of the “Standard” license, already described in the previous subchapter. However, noise calculation for the ThPA needed only 619 sources, without any attempt to reduce them, and the limit is 4000<sup>13</sup>, so it would take a port seven times larger to present possible problems and the need for the optimization of the number of sources.

### 6.4.3. How the model works

Once the problem to be modelled is set up and the assumptions are described, the actual modelling can proceed. The first step is to choose which calculation method would be used. The most convenient way would be to use

<sup>13</sup> <https://www.emsbk.com/wp-content/uploads/Product-Data-Predictor-LimA-BP1602-A4.pdf>

some of the calculation standards that support both industrial and traffic noise sources. There are two such standards implemented in the used software – CNOSSOS-EU and Harmonoise calculation standards. As Harmonoise is described as having “many phrases and formulae are still unclear and ambiguous” and “recommended only for experimental modelling”, CNOSSOS-EU was tested first.

The CNOSSOS-EU method is based on the Commission Directive (EU) 2015/996 of 19 May 2015. The directive was a part of the European Union plan to establish common noise assessment methods. The method has different formulas implemented based on the type of the source to be calculated, in this case: general/industrial, railway and road.

General equation for the noise level is the following:

$$L_{Aeq,T} = 10 \cdot \log \left( \sum_{i=1} 10^{(L_{eq,T,i} + A_i)/10} \right)$$

Road noise (per metre), based on the traffic flow, is calculated using the following basic formula<sup>14</sup>:

$$L_{W',eq,line,i,m} = L_{W,i,m} + 10 \cdot \log \left( \frac{Q_m}{1000 \cdot v_m} \right)$$

For the railway noise, the following formulas are used for the basic calculation if traffic flows are used<sup>15</sup>:

$$L_{W',eq,T,dir,i} = 10 \cdot \log \left( \sum_{x=1}^X 10^{L_{W',eq,line,x}/10} \right)$$

$$L_{W',eq,T,dir,i}(\psi, \varphi) = L_{W,0,dir,i}(\psi, \varphi) + 10 \cdot \log \left( \frac{Q}{1000 \cdot v} \right)$$

Noise indicator  $L_{DEN}$  is calculated with the following formula<sup>16</sup>:

$$L_{DEN} = 10 \cdot \log \left[ \frac{12}{24} \cdot 10^{L_{day}/10} + \frac{4}{24} \cdot 10^{(L_{evening} + 5)/10} + \frac{8}{24} \cdot 10^{(L_{evening} + 10)/10} \right]$$

However, there are several problems with the method. The first one is that it does not support adding data on weather conditions, such as wind, which were among the requirements of ThPA. The second problem is that the bug in the program prevents the method from finishing if there is at least one point source in the combination with other types of noise sources. This could be avoided by using short line sources in place of the point sources, but as the method doesn't support some meteorological data, it was decided that the other method should be used.

Harmonoise is a calculation method developed for the previously mentioned NoMEPorts project and was initially used only by the partners on the project. However, in the newer versions of the software, it is widely available. The equivalent sound pressure levels are calculated using the following formula for the sound pressure level, with  $n$  representing a source segment:

$$L_{eq1h,i,n} = L_{W,i} - A_{div} - A_{atm,j} - A_{excess,i} - A_{refl,i} - A_{scat,i}$$

Using Harmonoise calculation method, relatively accurate results were obtained, and, unlike CNOSSOS-EU method, it supports calculation of various scenarios based on different wind speeds and/or directions. However, other issues have arisen. The first one of them was extremely long calculation time, that could take up to 20 hours on average personal computers for the creation of the noise maps with a 25 m step grid. Calculation times

<sup>14</sup> [http://publications.europa.eu/resource/cellar/a2af495c-1fe0-11e5-a342-01aa75ed71a1.0006.02/DOC\\_1](http://publications.europa.eu/resource/cellar/a2af495c-1fe0-11e5-a342-01aa75ed71a1.0006.02/DOC_1)

<sup>15</sup> [http://publications.europa.eu/resource/cellar/a2af495c-1fe0-11e5-a342-01aa75ed71a1.0006.02/DOC\\_1](http://publications.europa.eu/resource/cellar/a2af495c-1fe0-11e5-a342-01aa75ed71a1.0006.02/DOC_1)

<sup>16</sup> [https://circabc.europa.eu/sd/a/6004362a-9169-4aed-ba33-73b46081f059/CNOSSOS-EU%20JRC%20Reference%20Report\\_V3\\_22%20September\\_2011\\_without%20authors.pdf](https://circabc.europa.eu/sd/a/6004362a-9169-4aed-ba33-73b46081f059/CNOSSOS-EU%20JRC%20Reference%20Report_V3_22%20September_2011_without%20authors.pdf)

for several points, if only receivers are used, took significantly less, but still a long time for a simple calculation – around 5 minutes. The other problem was the appearance of wrong calculations in some points.

As none of the calculation methods used for modelling all noise sources was usable, the other approach was used – the noise emissions of roads and railways were calculated using calculation methods specialized for those types of noise, as well as the two previously described ones, and then imported into an industrial noise calculation method as line sources. The only requirement was that the “final” calculation method (an industrial noise one) supports calculation using different wind speeds and directions.

For the final model, ISO 9613.1/2 was chosen, as it supports different wind directions and is based on the ISO-9613-1/2 and the ISO 17534-3 quality requirements. The formula used by the method is [predictor help]:

$$L_{lt,per} = L_{dw} - C_{m,per} - C_{t,per}$$

The next step is to create separate shape files for buildings, noise receivers and sources (one shape file for each source type). The source types used are described in subsection [6.5.?] and are as follows:

- Road traffic
- Railway
- Point sources – for vessels and stationary cranes
- Line source – moving crane
- Area sources – larger areas where many types of machinery (mostly related with cargo handling) are used

It is useful to enter the data about noise emissions in this step, so they would be automatically imported each time a shape file is imported. The data that has to be entered are described in the data requirements section. For traffic data, there are different ways of entering the data. In this case, traffic flow was used both for rail and road traffic.

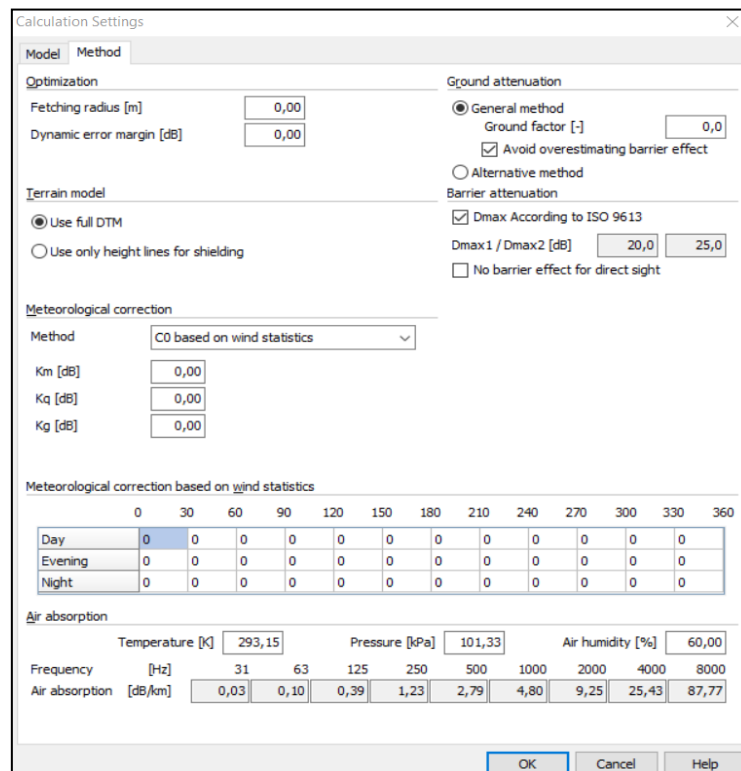


Figure 49 "Calculation Settings" in Predictor-LimA

When all the shape files are created and all of the relevant values are entered, the next step is to run a calculation. The two options that can be chosen are calculation points and calculation type. Choice of the calculation points

depends on the problem that needs to be solved, result requirements and the hardware used. If the creation of the noise map is required, grids should be used. However, if the calculation is done only for a few points (i.e. to compare with the measurement), it is easier and faster to use calculation in the receivers.

Some of the calculation times, based on the calculation points, are given in the table 16. Also, when height points are introduced, it significantly affects the calculation time. Number of calculation points used include three different scenarios – receivers only, receivers with grid (step 50m) and receivers with grid (step 25m). The grids are required when the objective is noise mapping. Receivers are enough to check the values in several control points. It is easy to see how the number of grid points and the introduction of height point affect the calculation time.

*Table 16: Computational time for noise modelling*

Calculation points	Height points (yes/no)	Time
10 (receivers only)	No	Few seconds
2220 (receivers and grid – 50m)	No	21 minutes
8918 (receivers and grid – 25m)	No	85 minutes
10 (receivers only)	Yes	1.5 – 2 minutes
2220 (receivers and grid – 50m)	Yes	3 hours

All of the simulations to assess the calculation time were done in the same conditions. Once the calculation settings are done, the calculation can be started. To sum up, the process can be divided into the following steps:

1. Choice of the calculation method
2. Importing (and, if needed, creation or modification) of the shape files containing position and emissions of noise sources
3. Choice of the calculation points and calculation type
4. Checking the errors in the model
5. Setting the calculation settings (reflections, meteorological data, ground data, etc.)

### **Noise mapping – example (ThPA)**

In the case of ThPA, the data was provided using several approaches. Spot heights, locations of the buildings, walls and locations of most of the sources were provided by the port using shape files (extension “.shp”). An exception to this were the heights of the buildings, which were provided using tables and were entered manually in Predictor. Another exception was the location of some noise sources. While roads, railways and docks locations were provided via shape files, the positions of stationary cranes and area sources had to be entered manually, using the noise maps provided in [noise\_map\_measurements\_2018.pdf].

Noise sensitive areas are mentioned in the same text (English translation provided by the port specifically for the use in the PIXEL project was used), although their location wasn't considered for the purposes of the initial model. The surface of the ground is assumed to be asphalt/concrete, so no ground attenuation was used for the simulation. Also, the locations of the receivers were entered manually based on the coordinates provided in the text.

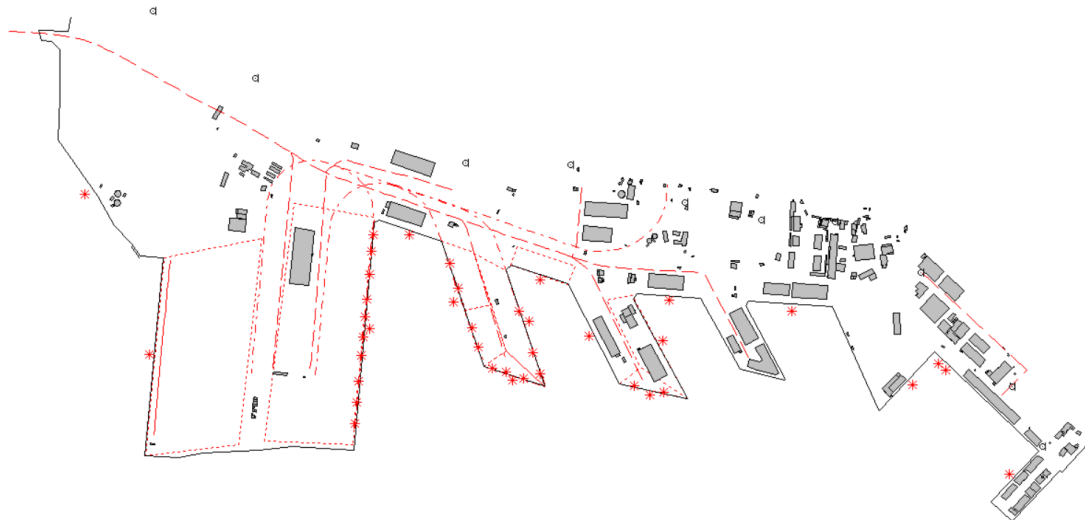


Figure 50: Locations of noise sources and buildings in the Port of Thessaloniki

The locations of all noise sources and buildings can be seen on the Figure 50. Red lines and points represent the sources, while the grey shapes are the structures – buildings and tanks. Black line is not used in the noise modelling, it represents only the border between the land and the sea. Height points were omitted for the sake of clarity, because they would cover most of the building and sources in the figure. It should be noted that in the final model (modelled using ISO 9613.1/2 method), as line sources were used instead of specialized lines for road and railway traffic, the differences between road, railway and industrial line sources could not be seen.

In this case, meteorological data was omitted or, better said, no meteorological correction was added, as the simulation in the THPA report did not mention any. For the ground data, the asphalt/concrete (no ground attenuation) was used, as it is a material that covers most of the ground in the Port of Thessaloniki.

In order to validate the results, the comparison with some previously done noise level calculations or measurements had to be done. As the Port of Thessaloniki has provided their yearly report, the model to estimate the influence of the port on the total noise level was created. The results obtained using the model were compared with those obtained by the company doing the simulation for the port’s yearly report.

Also, even if the data used is completely the same, some differences are also expected if different calculation methods and/or calculation software are used. There is also a possible influence of the buildings that were omitted in the report, but used in the PIXEL simulation. However, the results were almost the same (or at least very similar) for all of the receivers and can be seen in Table 18, with absolute and relative differences for each of the receivers. In the port’s report, only L<sub>night</sub> and LDEN results were shown, so the comparison is done for those two noise levels.

Table 17: Comparison of the results of the simulations conducted by ThPA and PIXEL

Receiver	L <sub>night</sub> (dB(A))				LDEN (dB(A))			
	ThPA	PIXEL	Abs. dif.	Rel. dif.	ThPA	PIXEL	Abs. dif.	Rel. dif.
1	51.2	53.1	1.9	3.58%	57.6	59.5	1.9	3.19%
2	39.1	42.1	3	7.13%	57.2	55.7	-1.5	-2.69%
3	40.2	41.7	1.5	3.6%	55.9	56.6	0.7	1.24%
4	40.3	39.5	-0.8	-2.03%	50.2	49.8	-0.4	-0.8%
5	42.6	43.7	1.1	2.52%	52.9	53.9	1	1.86%
6	44.1	44.9	0.8	1.78%	54.6	55.6	1	1.8%
7	45.3	47.3	2	4.23%	56.9	59.6	2.7	4.53%
8	46.7	49.2	2.5	5.08%	58.3	61.7	3.4	5.51%
9	43.7	43.8	0.1	0.23%	59.4	59.2	-0.2	-0.34%
10	41.2	41.3	0.1	0.24%	58.2	57.3	-0.9	-1.57%

While the values are very similar to those obtained by the ThPA partners, comparison with the regulated levels should still be done. There are two main limits set, according to the THPA report:



- $L_{DEN} = 70 \text{ dB (A)}$
- $L_{night} = 60 \text{ dB (A)}$

It is clear from the Table 18 that none of the results obtained by the PIXEL simulation comes close to these limits, so there is no question of the port activities overshooting those values in normal conditions.

Comparison of the noise maps obtained by the port’s contractors (Figure 52) and by the PIXEL project (Figure 53) is also provided.



Figure 51: Noise map from the ThPA yearly report

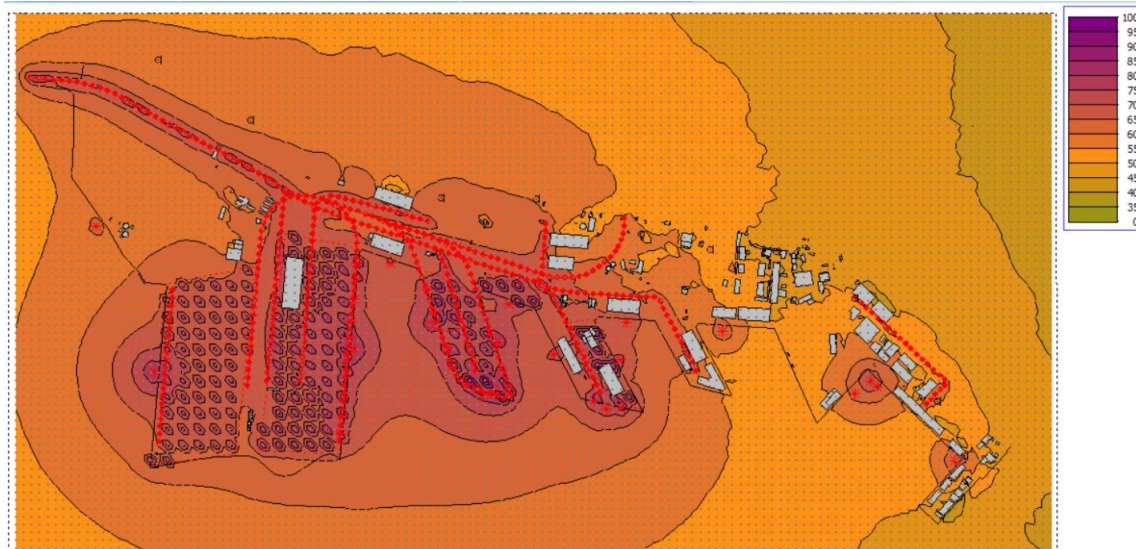


Figure 52: Noise map as done by PIXEL

Considering all of the above, it can be concluded that the model used is valid for noise modelling of port activities. Like all models, some assumptions had to be made and some simplifications were introduced. However, the results were comparable to those achieved by the ThPA (or, more precisely, the company that did the modelling). The two models were conducted using different noise calculation standards and PIXEL model featured more buildings than ThPA model, which accounts for few small differences in some of the receivers.

At the very end, a question of the usefulness of those models arises. As it was stated in the introduction to this subchapter, those models are very useful in assessing the influence that some noise pollutant (in this case, ThPA) has on their environment. It is sometimes the only way to assess the noise emissions from only one pollutant, as measurements often take into account neighbouring pollutants, such as roads, social events, construction works etc.

In a scenario where there is transgression of the regulated noise limits, those models can be used to optimize the activities, or build physical barriers, to reduce the noise pollution. In the case where there is no violation of the regulations, as is the case with ThPA, the models should be used to track those emissions and eventual changes that can occur as a result of increased port activities, including using models as a helping tool in the decision on the placements of the sensors. Also, in the case that there are planned expansions of the port, the plans can be tested with slight modification to the existing models.

## 6.4.4. Requirements for integration of noise pollution model in the PIXEL architecture

In the following section data and system requirements are defined for using Predictor-Lima. However, due to the fact that it is a commercial software Predictor Lima will not be directly integrated in the whole technological PIXEL framework. However, the methodology that have been described is fully replicable and transferable to small and medium European ports.

### 6.4.4.1. Data requirements

Before proceeding with specific requests for noise modelling, the port should answer the following questions:

1. Which traffic noise sources exist in the port area and the nearby area considered for noise mapping?
2. What is the exact location of those sources? (provided in the “geographical data”)
3. What data specific for each traffic noise source is measured and can be provided?

Considering the third question, each of the traffic noise sources has some specific data that is required for its modelling. The data requirements are directly obtained from the program used for the modelling (Predictor-LimA).

It should be noted that each input data should be given for three periods (the usual time periods are given in brackets): day (7:00-19:00), evening (19:00-23:00) and night (23:00-7:00).

*Table 18: Data requirements for road noise modelling*

<b>Road</b>	Modelling of the sound power output of road traffic. Given as a polynomial line where each point has its own height	
- height	Choice between absolute height, relative height, relative to item below or user defined height	m
- road width	Self-explanatory	m
- input type (volume input)	Choice between: <ul style="list-style-type: none"> <li>- distribution – hourly percentage of vehicles for each defined period (need to be done for 24). Should include estimations for the distribution of the traffic per category (motorcycles, light vehicles, light trucks and heavy trucks)</li> <li>- traffic flow – absolute number of vehicles for each type per hour (the types are again motorcycles, light vehicles, light trucks and heavy trucks)</li> <li>- emission – source power per period</li> </ul>	<p>% per hour</p> <p>Absolute number</p>

		Lw/m
- Pavement type	It influences the amount of emission vehicle using the road produce. Several types can be selected	
- Control device	Device that can impact the speed of the vehicles. It is related to the following properties: <ul style="list-style-type: none"> <li>- Speed constraints – specifies the speed that is used for a vehicle category</li> <li>- Percentage affected – percentage of the traffic affected by the device</li> </ul>	
- On structure?	Specifies if the road is situated on an elevated structure	
- Vehicle speeds	The cruising speed for each vehicle type (motorcycles, light vehicles, light trucks and heavy trucks)	km/h

Very similarly, the program has requirements for the railroad noise pollution modelling.

*Table 19: Data requirements for railway noise modelling*

<b>Railway</b>	Modelling of the sound emission of railway traffic. It is done using the shape of a polynomial line where each point has its own height.	
- height	Choice between absolute height, relative height, relative to item below or user defined height	m
- traffic flow	The following data need to be added: <ul style="list-style-type: none"> <li>- support correction,</li> <li>- track correction,</li> <li>- type of train</li> <li>- speed per category,</li> <li>- average hourly traffic flow per period</li> </ul>	km/h Vehicles/h
- speed	Different values need to be entered for passing trains and stopping trains and the speed of trains which apply the brakes has to be entered as a negative value	
- fraction stopping trains	Percentage stopping trains of the total number of train units (note: this information can also be provided in the “traffic flow” section. In that chase, there should be a note that the train is stopping)	%

At the end, it should be noted that instead of traffic data, the input for both road and railway noise can be given as average sound levels per length. However, those measurements might also include some noise sources unrelated to the traffic. For this reason, traffic data is strongly preferred in this case.

The third traffic noise source are moving ships (ships entering the port). The program doesn’t have a specific option for the modelling of the ships, but an item called “moving source” can be used.

*Table 20: Data requirements for moving sources*

<b>Moving source</b>	Modelling of the path of mobile sources, like track routes. It is modelled as a polyline with at least two points.	
- height	Terrain level of all source points compared to some fixed 0-level Height of all source points above that terrain level	m m
- emission	It is frequency dependent and A-weighted.	dB (A)
- length of the route segment	Self-explanatory	m
- average velocity	Self-explanatory	m/s
- working hours	Time correction is calculated based in the number of point sources, the velocity and the “flow” (traffic per time period)	dB
- flow	Used in time correction.	Vehicles/time period

Since the “emission” part is hard to measure for every ship, the port should provide data on ship types and their traffic flow, as well as the routes that those ships usually take.

Similarly, to traffic noise data, there are also noise sources that can be put together in the “industrial noise” category.

The NoMEPorts Project (more details on it are in the Appendix C4.3) mentions the following industrial noise sources:

- port services and facilities
- terminals (cargo handling, warehousing)
- industrial areas
- machinery and workshop
- vessel repair and maintenance
- shunting yards
- vessels when berthed (engine noise)

Like traffic noise, industrial noise sources also have the three questions related to them. However, unlike the traffic noise sources, industrial noise sources are far more varied and there is no specific model for each of them in the noise modelling software. All of them need to be modelled using either point sources, line sources or area sources.

Point sources should be used for:

- cranes
- lift-trucks
- coolers
- berthed vessels
- stationary machinery

Line sources are primarily used to model truck and machinery paths outside of the roads modelled with traffic noise data.

Area sources are used for larger noise sources:

- shunting yards
- industrial areas

All three kinds of sources used for the modelling of industrial noise share similar characteristics, with the only real difference being in the units in which the noise level is given. Their requirements are given in table [ ].

*Table 21: Data requirements for area, line and point sources*

<b>Area source</b>	Modelling of the industrial area sources with a specific sound power per m <sup>2</sup>	
- height	Choice between absolute height, relative height, relative to item below and user defined	m
- number of point sources	Distance between sources in X and Y direction, user defined	m
- emission	It is frequency dependent and A-weighted	dB (A)
- working hours	Used to derive a time correction (reduction), can be given in absolute numbers in dB or as a percentage	dB or %
<b>Line source</b>	Modelling of the sound power of industrial line sources with a specific sound power per m	
- height	Terrain level of all source points compared to some fixed 0-level Height of all source points above that terrain level	m m
- maximum distance between sources	Line is split into a fixed number of point sources, user defined [?]	m

- discard reflection	Used if the reflection of the closest building (up to 5m) shouldn't be calculated	
- discard attenuation	Used if the attenuation effect of the building or process area underneath the source shouldn't be calculated	
- sound power level	It is frequency dependent and A-weighted, defined as either Lw or Lw/m	dB (A) [dB (A)/m ?]
- working hours	Used to derive a time correction (reduction), can be given in absolute numbers in dB or as a percentage	dB or %
<b>Point source</b>	Modelling of the sound pressure level emission of various sound sources.	
- type	Choice between “normal point source” (emission is given by a direction angle and an aperture angle, there is no emission outside the aperture angle) and “emitting facade/roof” (emission direction parameters cannot be set and reflection effect is excluded)	
- height	Terrain level of all source points compared to some fixed 0-level Height of all source points above that terrain level	m m
- discard reflection	Used if the reflection of the closest building (up to 5m) shouldn't be calculated	
- discard attenuation	Used if the attenuation effect of the building or process area underneath the source shouldn't be calculated	
- sound power level	It is frequency dependent and A-weighted, defined as either Lw or Lw/m	dB (A) [dB (A)/m ?]
- working hours	Used to derive a time correction (reduction), can be given in absolute numbers in dB or as a percentage	dB or %

Additionally, data on some meteorological characteristics should be provided (the time period is planned to be one month, but it would be very useful to have data for extreme weather situations during the year):

- Wind speed (by direction and time of day – day, evening and night)
- Temperature (K)
- Pressure (kPa)
- Air humidity (%)

#### 6.4.4.2. System requirements

For the purposes of the noise mapping in the PIXEL project, Predictor (v12.00, 64-bit) software was used. The configuration used was “Standard”, type AU-7810-G. More about the program can be read in the appendix B4.4. Model sizes are the following<sup>17</sup> :

- Advanced – no limit for ISO 9613, DAL32 and RMR-RM2 methods, while the limit is 200,000 sources and 1,000,000 obstacle or terrain edges
- Plus – the limits are 12,000 sources, 60,000 obstacle edges and 1,000,000 obstacle or terrain edges
- Standard – the limits are 4,000 sources, 20,000 obstacle edges and 1,000,000 obstacle or terrain edges

Also, the manufacturer recommends the following minimal PC configuration<sup>18</sup>:

- Microsoft Windows 10, 64-bit operating system (although Windows 7, 8 and 10, both 32- and 64-bit can be used)
- Intel or Nvidia graphics adaptor
- 8 GB RAM
- At 1 GB of free disk space, with additional space reserved for working

<sup>17</sup> <https://www.emsbk.com/wp-content/uploads/Product-Data-Predictor-LimA-BP1602-A4.pdf>

<sup>18</sup> <https://www.emsbk.com/wp-content/uploads/Product-Data-Predictor-LimA-BP1602-A4.pdf>

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# Appendix A – Data models for PAS

## A.1 Vessel calls data model

No.	Property	Values	Notes
1	Identification		General Vessel identification values.
1.1	Ship_ID	Text	As IMO number.
1.2	Arrival_Time	Date and time.	Estimated or real time.
1.3	Departure_Time	Date and time.	Estimated or real time.
1.4	Docking_Area	ID of a specific docking area	See Area data model.
2	Cargo		Cargo related values.
2.1	Cargo_type	To coincide with the predefined (by the user) list of cargo.	<p>User should be able to interfere with this property if the vessel call does not coincide with the predefined cargo list (and consequently the predefined supply chain scenarios).</p> <p>In case a scenario for the amount of cargo does not exist (and the user will not create one), a default scenario has to be created.</p> <p>The user should be able to act on the vessel calls or (preferably) in the resulting cargo queue as described in 3.2.3.</p>
2.2	Cargo_Units	Select from: <ul style="list-style-type: none"> <li>- t</li> <li>- l</li> <li>- cu.m.</li> <li>- Containers</li> </ul>	This field is for correct model execution as described in the machines and area data models.
2.3	Cargo_Amount	Number in Cargo_Units	It is assumed that the whole amount of cargo will be handled in the port. This will be able to be changed in the resulting cargo queue manually.
2.4	Cargo_Operation	Select between “Load”, “Unload” and “Unload / Load”.	<ol style="list-style-type: none"> <li>1. A loaded ship docks and unloads its cargo after its arrival time.</li> <li>2. An unloaded ship docks and is loaded with cargo before its departure time.</li> <li>3. A loaded ship docks and unloads its cargo after the arrival time and might be loaded with cargo before its departure time. In that case, two different entries in the cargo queue to be created.</li> </ol>

## A.2 Equipment data model

### A.2.1 Fixed Machines

No.	Property	Values	Notes
1	Identification		General equipment identification values.
1.1	ID	Text	<p>This property will be used as <b>unique</b> identifier of every unit of equipment. The users (ports) are able to use their preferred naming convention.</p> <p>Examples:</p> <ul style="list-style-type: none"> <li>- TrellexFLEXOPIP_1</li> <li>- Pipeline_huile_42b</li> <li>- StéréoL507_old</li> </ul>
1.2	Machine_Type	<p>Text based on predefined types (based on the ports equipment survey until the time this report had been released):</p> <ul style="list-style-type: none"> <li>- Fixed Crane</li> <li>- Rail Crane</li> <li>- Mobile Crane</li> <li>- Fixed Arms</li> <li>- Berth Connection</li> <li>- Conveyor Belt</li> <li>- Pipeline</li> <li>- Flexible Hoses</li> <li>- Terminal lighting</li> <li>- Pneumatic Conveyor</li> <li>- Screw Conveyor</li> <li>- Hopper</li> </ul> <p>User to be able to insert new type.</p>	<p>The usage of this field is for user convenience:</p> <ol style="list-style-type: none"> <li>1. To categorize different brands of same type of machinery.</li> <li>2. To allow the user to explore the possibility of usage of different type of machinery.</li> </ol> <p>The user should be able to modify the predefined types of machinery although it has been observed that different ports give different names to the same type of machinery. A default list is provided.</p>
1.3	Model	Text	Same as 1.2, this is for user convenience. The field can be left empty without consequences to the PAS.
1.4	Owner	<ul style="list-style-type: none"> <li>- Text based on predefined owners if available.</li> <li>- “Terminal” if not available.</li> </ul>	<p>This is to prevent the models from using for a supply chain machinery of different owner.</p> <p>If the user will not set any owners, the default value can be “Terminal”.</p>
1.5	Terminal	<ul style="list-style-type: none"> <li>- Text based on predefined Terminals if available.</li> <li>- “Default” if not available.</li> </ul>	<p>Same as 1.4 for usage in different terminals.</p> <p>If the user will not set any owners, the default value can be “Default”.</p>
1.6	Picture	Link to a URL, or upload, or leave blank.	This field is for user convenience. Users to provide the pictures themselves. The field can be left empty without consequences to the PAS.

2	Specifications		General equipment specifications values.
2.1	Energy_Type	Select from (or to add new type): <ul style="list-style-type: none"> <li>- Electrical (Battery)</li> <li>- Electrical (Mains Connection)</li> <li>- Diesel</li> <li>- Gasoline</li> <li>- LNG</li> </ul>	Until now, ports are not specifying the exact type of Diesel. Since current emissions are calculated on diesel fuel E3 (EMEP/EEA & IPCC), any change on this will affect the models precision.
2.2	Power	Insert equipment power in kW.	Since consumption is not readily available from ports, models can rely on Power as described in 3.2.2.1.
2.3	Consumption_Units	Select from (for fixed machines): <ul style="list-style-type: none"> <li>- l/h</li> <li>- kWh</li> </ul>	None.
2.4	Throughput_Units	Select from: <ul style="list-style-type: none"> <li>- t/h</li> <li>- l/h</li> <li>- cu.m./h</li> <li>- Containers/h</li> </ul>	<p>This field is for correct model execution. If the user describes a pump to unload crude oil and this pump is inserted into a container supply chain, the error will be easily detectable and the calculations will not rely on a pump carrying multiple containers per time unit.</p> <p>Containers/h is being used since for some equipment (e.g. cranes) TEUs is not used – the norm in ports for container handling throughput is “moves per hour” which implies “containers per hour”.</p>
2.5	Usability		
2.5.1	Current_State	Select from: <ul style="list-style-type: none"> <li>- Available</li> <li>- Not available</li> </ul>	<p>This field will allow user to temporarily decommission machinery for maintenance.</p> <p>This field is <b>not</b> for user to change every time the machinery is being used on another supply chain, as the PAS should be able to do those assignments by itself.</p>
2.5.2	Working Hours		
2.5.2.1	Start	Insert time or “Same as port operating hours”	According to the ports for the machinery surveyed until the moment this report was written, these values coincide with the shifts starting and ending hours – i.e. when the port is operating.
2.5.2.2	End	Insert time or “Same as port operating hours”	
2.5.3	Weather Limits		
2.5.3.1	Wind	Insert value in kph or N/A.	This will prevent the model from simulating equipment that will not be able to be used under certain conditions. For example, cranes are limited in their operation when wind exceeds certain limits (different for each crane). For comments on Rainfall and Temperature see 3.2.1.5.
2.5.3.2	Rainfall	Insert value in mm/h or N/A.	
2.5.3.3	Temperature	Insert value in °C or N/A.	

2.6	Default Operation		<p>The values below are the default values of throughput and consumption of the machine.</p> <p>If the user will insert special values for each type of cargo the machine will be used for, those values (2.6.1 and 2.6.2) will be disregarded by the model.</p> <p>If the user will not insert special values for one type of cargo the machine will be used for, the values 2.6.1 and 2.6.2 will be used by the model only for that type of cargo.</p> <p>Consequently, if the user will not insert special values for any type of cargo the machine will be used for, the values 2.6.1 and 2.6.2 will be used by the model for any type of cargo.</p>
2.6.1	Default_Consumption	Number in “Consumption_Units” [2.3] or “Rely on power”	<p>If the consumption of the machinery for a cargo operation is not available, then the model can rely on the power output of the machine based on assumptions that are analyzed in 3.2.2.1.</p> <p><u>In that case the model accuracy will be reduced.</u></p>
2.6.2	Default_Throughput	Number in “Throughput_Units” [2.4] or “Same as Supply Chain”	<p>If the throughput of the machine for a cargo operation is not available, the model can use the throughput of the supply chain.</p> <p><u>In that case the model accuracy will be reduced.</u></p>
3	Operations		<p>In this set of values, the user will be able to insert for every different type of cargo the throughput and the consumption of the machinery. In that case, the model accuracy will be increased.</p> <p>As noted above, if this kind of data is not available, the user will not fill-in any specific set of values and the model will use the default values 2.6.1 and 2.6.2. <u>In that case, the model accuracy will be reduced.</u></p>
3.1	Cargo 1		
3.1.1	Suitable_Cargo_Type_1	Select from the predefined (by the user) list of cargo.	None.
3.1.2	Consumption_1	Same as 2.6.1	Same as 2.6.1
3.1.3	Throughput_1	Same as 2.6.2	Same as 2.6.2
3.2	Cargo 2		
3.2.1	Suitable_Cargo_Type_2	Select from the predefined (by the user) list of cargo.	None.
3.2.2	Consumption_2	Same as 2.6.1	Same as 2.6.1
3.2.3	Throughput_2	Same as 2.6.2	Same as 2.6.2
...			

3.N	Cargo N		
3.N.1	Suitable_Cargo_Type_N	Select from the predefined (by the user) list of cargo.	None.
3.N.2	Consumption_N	Same as 2.6.1	Same as 2.6.1
3.N.3	Throughput_N	Same as 2.6.2	Same as 2.6.2
4	Comments		General comments by the user such as “Out of order since ...” or “Detailed emissions data not yet submitted by the supplier”, etc.  Comments should be erasable.
4.1	Comment 1		
4.1.1	Comment_1	Text	None.
4.1.2	Date_Time_1	Insert automatically date and time	None.
4.2	Comment 2		
4.2.1	Comment_2	Text	None.
4.2.2	Date_Time_2	Insert automatically date and time	None.
...			
4.N	Comment N		
4.N.1	Comment_N	Text	None.
4.N.2	Date_Time_N	Insert automatically date and time	None.

### A.2.2 Mobile Machines

No.	Property	Values	Notes
1	Identification		General equipment identification values.
1.1	ID	Text	Same as with fixed machines.
1.2	Machine_Type	Text based on predefined types (based on the ports equipment survey until the time this report had been released): <ul style="list-style-type: none"> <li>- Straddle Carrier</li> <li>- Stacker</li> <li>- Loader (Low Capacity)</li> <li>- Loader (Medium Capacity)</li> <li>- Loader (High Capacity)</li> </ul>	Same as with fixed machines.  <b>The predefined values list is different than that of the fixed machines.</b>

		<ul style="list-style-type: none"> <li>- Forklift</li> <li>- Dump Truck</li> <li>- Tank Truck</li> <li>- Terminal Tractor</li> <li>- Rail Mounted Gantry</li> <li>- Rubber Tire Gantry</li> <li>- Car</li> <li>- Truck</li> <li>- Bus</li> <li>- Motorcycle</li> <li>- Tractor</li> </ul> <p>User to be able to insert new type.</p>	
1.3	Model	Text	Same as with fixed machines.
1.4	Owner	<ul style="list-style-type: none"> <li>- Text based on predefined owners if available.</li> <li>- “Terminal” if not available.</li> </ul>	Same as with fixed machines.
1.5	Terminal	<ul style="list-style-type: none"> <li>- Text based on predefined Terminals if available.</li> <li>- “Default” if not available.</li> </ul>	Same as with fixed machines.
1.6	Picture	Link to a URL, or upload, or leave blank.	Same as with fixed machines.
2	Specifications		General equipment specifications values.
2.1	Energy_Type	<p>Select from (or to add new type):</p> <ul style="list-style-type: none"> <li>- Electrical (Battery)</li> <li>- Electrical (Mains Connection)</li> <li>- Diesel</li> <li>- Gasoline</li> <li>- LNG</li> </ul>	Same as with fixed machines.

2.2	Power	Insert equipment power in kW.	Same as with fixed machines.
2.3	Consumption_Units	Select from (for moving machines): <ul style="list-style-type: none"> <li>- l/h</li> <li>- kWh</li> <li>- l/100km</li> <li>- km/l</li> <li>- m/g</li> </ul>	Same as with fixed machines.  <b>The predefined values list is different than that of the fixed machines: it has fuel consumption per distance also inserted.</b>
2.4	Capacity_Units	Select from (for moving machines): <ul style="list-style-type: none"> <li>- t</li> <li>- l</li> <li>- cu.m.</li> <li>- Containers</li> </ul>	This field is for correct model execution. If the user describes a tank truck to carry crude oil and this tank truck is inserted into a container supply chain, the error will be easily detectable and the calculations will not rely on a truck carrying multiple containers per trip.  Containers is being used since for some equipment (e.g. cranes) TEUs is not used – the norm for the throughput of container handling in ports is “moves per hour” which implies “containers per hour”. So, this must be the same throughout all supply chain.
2.5	Usability		
2.5.1	Current_State	Select from: <ul style="list-style-type: none"> <li>- Available</li> <li>- Not available</li> </ul>	Same as with fixed machines.
2.5.2	Working Hours		
2.5.2.1	Start	Insert time or “Same as port operating hours”	Same as with fixed machines.
2.5.2.2	End	Insert time or “Same as port operating hours”	
2.5.3	Weather Limits		
2.5.3.1	Wind	Insert value in kph or N/A.	Same as with fixed machines.
2.5.3.2	Rainfall	Insert value in mm/h or N/A.	
2.5.3.3	Temperature	Insert value in °C or N/A.	
2.6	Default Operation		The values below are the default values of capacity, fully loaded machinery consumption and fully loaded machinery consumption.  If the user will insert special values for each type of cargo the machine will be used for, those values (2.6.1, 2.6.2 and 2.6.3) will be disregarded by the model.  If the user will not insert special values for one type of cargo the machine will be used for, the



			<p>values 2.6.1, 2.6.2 and 2.6.3 will be used by the model only for that type of cargo.</p> <p>Consequently, if the user will not insert special values for any type of cargo the machine will be used for, the values 2.6.1, 2.6.2 and 2.6.3 will be used by the model for any type of cargo.</p> <p>Since this type of machinery will be making round trips (1. loaded for the trip from cargo origin to cargo destination and 2. empty for the trip from cargo destination to cargo origin) the values for consumption and speed when the equipment will be empty are also requested.</p>
2.6.1	Default_Loaded_Consumption	Number in “Consumption_Units” [2.3] or “Rely on power”	<p>If the consumption of the machinery for a cargo moving operation is not available, then the model can rely on the power output of the machine based on assumptions that are analyzed in 3.2.2.1 operating at 80% of expected maximum power.</p> <p><u>In that case the model accuracy will be reduced.</u></p>
2.6.2	Default_Capacity	Number in “Capacity_Units” [2.4] or “Reverse calculate from Supply Chain”	<p>If the capacity of the equipment for a cargo moving operation is not available, the model can use the throughput of the supply chain.</p> <p><u>In that case the model accuracy will be <b>greatly</b> reduced.</u></p>
2.6.3	Default_Loaded_Speed	Number in kph	<p>If the loaded speed of the machine for the specified cargo operation is not available, the model can use the maximum speed allowed inside the port for operations.</p> <p><u>In that case the model accuracy will be <b>greatly</b> reduced.</u></p>
2.6.4	Empty_Consumption	Number in “Consumption_Units” [2.3] or “Rely on power”	<p>If the consumption of the machinery for moving while being empty is not available, then the model can rely on the power output of the machine based on assumptions that are analyzed in 3.2.2.1 operating at 50% of expected maximum power.</p> <p><u>In that case the model accuracy will be reduced.</u></p>
2.6.2	Empty_Speed	Number in kph.	<p>If the loaded speed of the machine for the specified cargo operation is not available, the model can use the maximum speed allowed inside the port for operations.</p> <p><u>In that case the model accuracy will be reduced.</u></p>
3	Operations		<p>In this set of values, the user will be able to insert for every different type of cargo the capacity, the consumption and the speed of the machinery. In that case, the model accuracy will be increased.</p> <p>As noted above, if this kind of data is not available, the user will not fill-in any specific set of values and the model will use the default values 2.6.1, 2.6.2 and 2.6.3. <u>In that case, the model accuracy will be reduced.</u></p>

3.2	Cargo 1		
3.2.1	Suitable_Cargo_Type_1	Select from the predefined (by the user) list of cargo.	None.
3.2.2	Capacity_1	Same as 2.6.1	Same as 2.6.1
3.2.3	Consumption_1	Same as 2.6.2	Same as 2.6.2
3.2.4	Speed_1	Same as 2.6.3	Same as 2.6.3
3.3	Cargo 2		
3.3.1	Suitable_Cargo_Type_2	Select from the predefined (by the user) list of cargo.	None.
3.2.2	Capacity_2	Same as 2.6.1	Same as 2.6.1
3.3.3	Consumption_2	Same as 2.6.2	Same as 2.6.2
3.3.4	Speed_2	Same as 2.6.3	Same as 2.6.3
...			
3.N	Cargo N		
3.N.1	Suitable_Cargo_Type_N	Select from the predefined (by the user) list of cargo.	None.
3.2.2	Capacity_N	Same as 2.6.1	Same as 2.6.1
3.N.3	Consumption_N	Same as 2.6.2	Same as 2.6.2
3.N.4	Speed_N	Same as 2.6.3	Same as 2.6.3
4	Comments		General comments by the user such as “Out of order since ...” or “Detailed emissions data not yet submitted by the supplier”, etc. Comments should be erasable.
4.1	Comment 1		
4.1.1	Comment_1	Text	None.
4.1.2	Date_Time_1	Insert automatically date and time	None.
4.2	Comment 2		
4.2.1	Comment_2	Text	None.
4.2.2	Date_Time_2	Insert automatically date and time	None.
...			
4.N	Comment N		
4.N.1	Comment_N	Text	None.
4.N.2	Date_Time_N	Insert automatically date and time	None.

## A.3 Areas data model

No.	Property	Values	Notes
1	Identification		General area identification values.
1.1	ID	Text	This property will be used as <b>unique</b> identifier of every area. The users (ports) are able to use their preferred naming convention.  Examples: <ul style="list-style-type: none"> <li>- Bassens_Liquid_Bulk_Storage_19</li> <li>- Bassens_Berth_42</li> </ul>
1.2	Area_Type	Text based on predefined types (based on the ports areas until the time this report had been released): <ul style="list-style-type: none"> <li>- Docking Area</li> <li>- Storage Area</li> <li>- Gate</li> </ul> User to be able to insert new type.	The usage of this field is for user convenience: 1. To categorize different areas of same use. 2. To allow the user to explore the aggregated power or emissions of each area.  The user will be able to modify the predefined types of areas. A default list is provided.
1.3	Suitable_Cargo_Type	Select (multiple selection) from the predefined (by the user) list of cargo.	This field is for correct model execution. If the user describes a warehouse for cereal, this should not be able to be accepted in a container handling supply chain. By making this distinction for an area, the error will be easily detectable.
2	Consumption		Areas Consumption values. This can be left blank without consequences for the correct execution of the PAS.
2.1	In Use		Values for when the area is being used in an active supply chain.
2.1.1	Lights_with_Sunlight	Units in KWh	Example: A warehouse will need lights during supply chain execution even during daytime.
2.1.2	Lights_without_Sunlight	Units in KWh	None.
2.1.3	Thermal_Regulation	Units in KWh	Example: A regulated liquid storage tank.
2.1.4	Other	Units in KWh	Example: Reefer storage area.
2.1	Not In Use		Values for when the area is <b>not</b> being used in an active supply chain.
2.1.1	Lights_with_Sunlight	Units in KWh	Example: Offices in a warehouse not currently active in a supply chain.
2.1.2	Lights_without_Sunlight	Units in KWh	None.
2.1.3	Thermal_Regulation	Units in KWh	Example: The same regulated liquid storage tank of [2.1.3].
2.1.4	Other	Units in KWh	Example: The same reefer storage area of [2.1.4].
3	Comments		General comments by the user such as “Not to be used since ...” or “Will be converted to cereal silo on...”, etc.  Comments should be erasable.
3.1	Comment 1		

3.1.1	Comment_1	Text	None.
3.1.2	Date_Time_1	Insert automatically date and time	None.
3.2	Comment 2		
3.2.1	Comment_2	Text	None.
3.2.2	Date_Time_2	Insert automatically date and time	None.
...			
3.N	Comment N		
3.N.1	Comment_N	Text	None.
3.N.2	Date_Time_N	Insert automatically date and time	None.

## A.4 Restrictions data model

No.	Property	Values	Notes
1	Default		Default restrictions for all kind of cargo handled.
1.1	Default_Wind_restriction	Insert value in kph or N/A.	
1.2	Default_Rainfall_restriction	Insert value in mm/h or N/A.	
1.3	Default_Temperature_restriction	Insert value in °C or N/A.	
2	Specific restrictions <b>or</b> cargo list		Default restrictions for each kind of cargo handled.
2.1	Cargo_Type_1	Select from the predefined (by the user) list of cargo, or use this list as list of predefined cargo list.	
2.1.1	Cargo_Units_!	Select from: - t - l - cu.m. - Containers	This field is for correct model execution as described in the machines and area data models.
2.1.2	Wind_restriction_1	Same as [1.1]	
2.1.3	Rainfall_restriction_1	Same as [1.2]	
2.1.4	Temperature_restriction_1	Same as [1.3]	
2.2	Cargo_Type_2	Same as [2.1]	
2.N.1	Cargo_Units_2	Same as [2.1.1]	Same as [2.1.1]
2.N.2	Wind_restriction_2	Same as [1.1]	
2.N.3	Rainfall_restriction_2	Same as [1.2]	

2.N.4	Temperature_restriction_2	Same as [1.3]	
...			
2.N	Cargo_Type_N	Same as [2.1]	
2.N.1	Cargo_Units_N	Same as [2.1.1]	Same as [2.1.1]
2.N.2	Wind_restriction_N	Same as [1.1]	
2.N.3	Rainfall_restriction_N	Same as [1.2]	
2.N.4	Temperature_restriction_N	Same as [1.3]	

## A.5 Scenario data model

No.	Property	Values	Notes
1	Identification		General scenario identification values.
1.1	ID	Text	This property will be used as <b>unique</b> identifier of every scenario. The users (ports) are able to use their preferred naming convention.  Examples: <ul style="list-style-type: none"> <li>- SC_Containers_RMG_Import</li> <li>- SC_Containers_RTG_Export</li> <li>- SC_Cereals_Import</li> </ul>
1.2	Cargo_Type	Select (multiple selection) from the predefined (by the user) list of cargo.	This field is for correct model execution as described in the machines and area data models.
1.3	Quantity_Units	Select from: <ul style="list-style-type: none"> <li>- t</li> <li>- l</li> <li>- cu.m.</li> <li>- Containers</li> </ul>	This field is for correct model execution as described in the machines and area data models.
1.4	SC_Throughput	Numerical value expressed in Quantity_Units per hour.	This will be used if the machines do not have separate throughputs assigned in them (low accuracy model).
2	Placement		The two areas the scenario is taking place.
2.1	Area-Origin	Select one from the areas specified in the areas data model.	None.
2.2	Area-Destination	Select one from the areas specified in the areas data model.	None.
3	Equipment		
3.1	Machine 1		
3.1.1	Machine_1	Select one from the machines specified in the machines data model.	Machine can be either mobile or fixed.

3.1.2	Sequence_Next_Machine_1	Select either “>” or “>>”	<ul style="list-style-type: none"> <li>- Symbol “&gt;” denotes that machine no. N+1 will <b>start any time after</b> machine no. N.</li> <li>- Symbol “&gt;&gt;” denotes that machine no. N+1 will <b>start only after</b> machine no. N <b>has finished</b>.</li> </ul> <p>Usage of symbol “&gt;&gt;” should take place <b>only</b> if machine throughput is specified for each machine of the supply chain.</p> <p>If the supply chain throughput is not calculated by the equipment throughput and it is only estimated in [1.4] (SC_Throughput), the model accuracy will be low, however calculations should be able to take place under the assumption that all machines start working simultaneously and for the same amount of time.</p>
3.1.3	Route_Length_1	Value in meters.	<p>Distance the <b>loaded</b> mobile machine is covering during the operation. The model will automatically make one calculation for energy consumption of a loaded machine and one calculation for an empty machine (returning to its origin in order to be loaded with new cargo).</p> <p>If this value is not null for fixed machines, the model will disregard it.</p>
3.2	Machine 2		
3.2.1	Machine_2	Same as 3.1.1	Same as 3.1.1
3.2.2	Sequence_Next_Machine_2	Same as 3.1.2	Same as 3.1.2
3.2.3	Route_Length_2	Same as 3.1.3	Same as 3.1.3
...			
3.N	Machine N		
3.2.1	Machine_N	Same as 3.1.1	Same as 3.1.1
3.2.2	Sequence_Next_Machine_N	Same as 3.1.2	Same as 3.1.2
3.2.3	Route_Length_N	Same as 3.1.3	Same as 3.1.3

# Appendix B - Links with others WP

The goal of this appendix is to introduce the PIXEL models as part of the PIXEL project. Firstly, we link PIXEL models with WP3 (Requirements and use cases) work and the technical description of the case studies with a focus on data analysis and modelling. We specify the elements resulting from deliverable D3.3 and D3.4 with a clear focus on modelling and data analysis. Secondly, we describe how PIXEL models will interact with WP5 (Port Environmental Index Development) and how emissions quantifications could be used in the Port Environmental Index (PEI). Thirdly, we show how PIXEL models will be integrated in the operational tools. The objective here is to highlight the needs and constraints of the PIXEL models towards the data management and overall architecture of PIXEL's Operational Tools. Finally, we discuss the link with the implementation and test of the PIXEL models in WP7 (Pilots trials integration, deployment and evaluation).

## B.1 WP3: Technical description of ports activities for modelling and data analysis

### B.1.1 Port of Bordeaux

#### *Port process description*

In D3.4 (Use cases and scenarios manual), GPMB defined the specific actions of its use case, primarily focused on energy modelling. Given that the use case is located at Bassens, the actions that require modelling are related only to ships dealing with good (Bassens do not manage passengers' calls). Indeed, in order to predict energy consumptions on a port terminal from expected vessels calls, it is needed to analyse the different processes of loading/unloading goods. The modelling needs are fully expressed by the energy manager scenario (GPMB-EM-1) described in D3.4: *Thanks to the knowledge of port's operations processes and to the data collected, modelling, simulations and predictive algorithms will be created in order to assess the opportunity to invest in photovoltaic rooftops and in the improvement of the port electricity network and especially in energy storage.* This energy model will use some data acquired by the statistics manager scenario (GPMB-StM-1) (ship call info). It will be used by the energy manager scenario (GPMB-EM-2) in order to analyse the distribution structure of electrical energy in Bassens and combined with environmental models it will allow to estimate environmental impacts due to the energy use inside the port ecosystem (Environmental manager scenario (GPMB-EnvM-1). The port agent scenario (GPMB-PA-1) will be able to interact with GPMB-EM-1 in order to obtain more detailed data that can get more accurate results (terminal operator can provide specific info about machinery). Finally, all the results obtained from the energy model will be used for decision-making by the port manager scenario (GPMB-PM-1) since the models are oriented to provide some hints for the potential feasibility on green energy investment.

Starting with the ideal port, WP4 team has leveraged all data available to get as close as possible to it, then to perform the modelling and simulation. In order to cover 100% of loading/unloading cases, five different logistics schemes have been described (based on GPMB experience in maritime logistics):

- import/export of containers,
- imports of handled solid bulks,
- exports of handled solid bulks,
- imports / exports of non-handled solid bulks,
- imports / exports of liquid bulks.

Following the definition of these five types of supply chain, it was decided to focus only on two supply chains on which the models of energy consumption will be tested and validated (development in WP4 and test in WP7). It is corn for export and pillared glass for import. This choice was made due to real difficulties to obtain data

about machine specifications and to deeply describe the supply chain steps. For these two supply chains, we were able to meet, exchange and validate our modelling approach directly with the operator of the associated port terminal. So, the supply chain descriptions are based on real process and not on average assumptions.

It is planned (based on scenarios described in D3.4) that simulation will be able to predict, at least:

- i) energy consumption related to ships operations and involved logistics chain,
- ii) energy to cover consumption needs of the port (how much green energy the port could provide and anticipate how much will be needed).

One objective of the energy modelling is to include the following items:

- lightning,
- buildings near the area of loading/unloading ships,
- consumption of different engines of machinery when loading/unloading cargo to/from vessels,
- reefers consumption,
- weather and other contextual information.

The consumption planning will be done based on these values. Next, to apply this modelling to other ports or use-cases only the values and pieces of the process should be changed, and the model should automatically adapt to a particular case.

### ***Modelling needs***

The global needs of the GPMB to model and analyse its energy consumption and production are described using users' stories approach. The scenarios and user stories are presented in D3.4 but for D4.2 there is a focus on the modelling needs.

**As a port agent/operator, I want to master my energies consumptions so that I can save money by optimising these consumptions. I also want to buy cheaper green electricity so that I can save money and contribute to actions for climate change. To do so, as a port manager, I want to estimate if the investment in solar panels on the rooftops of the port's warehouses is valuable so that I can decide whether to invest or not.**

In order to achieve these global needs modelling and data analysis will be focused on ships operations to predict energy consumptions – both models and predictive algorithms could be used depending on the level of accuracy of the information in possession of GPMB for each case – on a port terminal from expected vessels calls and on energy production using solar energy. We focus on this point because having the ability to predict the energy consumption due to the arrivals of a specific cargo will help the port to better plan its energy use. Another point to focus is the modelling of the energy production through solar panels. If we want to assess the possibility that the port can be a green electricity provider a prediction/ simulation of the energy production capacity is needed. This task is addressed in T4.5 and is reported in D4.4.

These needs are described with the following users' stories.

### **Modelling the energy consumption**

**As a statistics manager, I want to analyse the structure and periodicity of ships calls from the internal database including notions of time of call, goods, tonnages, berth, etc, so that I could estimate the average call time of a targeted good taking into account the wharf and a potential seasonality.**

This is a first step to do because energy demand (through the supply chain) directly depends on ships calls. This analysis will help the port to better understand its activity and then its energy demand. For now, this information is already available in GPMB database but not yet analysed. The loading / unloading rate is not the same for a similar good on a wharf (for instance grains) especially due to crane or conveyor belt used. Seasonality is also



important since for a same good, ships are bigger or not depending on harvest season or not. Information in the database owned by GPMB should allow to identify these parameters

**As an energy manager, I want to evaluate/quantify the energy consumption of each logistic chain model identified** by using measuring of the consumption of each element relating to loading/unloading considering technical features, so that I could **determine the relative share of each energy in the targeted logistic model and identify the potentially interesting elements for renewable energy injection.**

This is the second step of the modelling part. We want to model the supply chain for different types of cargo based on machine specifications and activity. We aim to be able to estimate in advance (a day or a week) what will be the energy consumption due to loading/unloading boat. This will help the port to better plan its energy use.

**As an energy manager, I want to obtain an average value of energy consumption for each element whose actual data would not be available** based on technical characteristics of the machines so that I could substitute a missing item by an average value.

In order to take this into account, the energy model will allow end-users to use different type of data: scaled, screening or comprehensive data. This will allow ports to use their own data but also average or similar data for those they cannot have access or obtain with a good precision.

**As an energy manager, I want to link the results of modelling,** namely: ships call data analysis and energy consumption of the logistics chains, so that I could **determine the energy consumption of any ship that has called** in the past and estimate the likely energy consumption of future ships whatever their goods.

This data processing will allow other features such as predicting the energy consumption of a vessel that has never called at Bordeaux by considering the parameters mentioned earlier as the size of the vessel (in taking a similar vessel) with tonnage and goods. These extrapolations and analyses will enable GPMB to determine in advance a reliable range of energy consumption.

**As an energy manager, I want to analyse the distribution structure of electrical energy from sensors available** on the entire terminal, so that I could **study from a data collection platform the consumption structure of all or part of a targeted area** in order to distribute the adequate proportion of electricity according to needs.

Today smart sensors are available at Bassens but they have to be connected to a platform that can gather and analyse data. The objective is to have a data analysis (based on past data) in order to predict the energy consumption of terminal operators.

### Modelling of the energy production

**As an energy manager, I want to predict/measure the real conditions of sunshine from a weather station** located in the port in Bassens, so that I could **evaluate precisely the amount of solar energy produced and adapt the need of conventional energy.** I could also **accurately determine** the handling downtime due to rain or wind type.

GPMB aims to know in advance what will be the potential of energy production using solar panels. This simulation/prediction tools could be based on data coming for external resources, based on a historical data sets or based on results on a weather simulation tools or service. In fact, the station is not designed to predict but to record what happened. This will be used to analyse the gap between tools like PVGIS ([http://re.jrc.ec.europa.eu/pvg\\_static/methods.html](http://re.jrc.ec.europa.eu/pvg_static/methods.html)) or similar tools estimations and the real situation. The energy prediction algorithms are fully addressed in task 4.5 and will be fully reported in deliverable D4.4.

### Data available and/or to be collected

In order to predict the energy consumption of cargo supply chain, PIXEL methodology needs to know the specifications of engine, of cargo of every day of the year, energy production of photovoltaic panel and weather in the port. This would be the ideal data.

Table 22: Data available and/or to be collect in GPMB

Data needed	Available	To be collected	Means of transmission	Frequency	End-points
Estimated costs of works on a warehouse (solar panels, reinforcement of rooftops structure...)	Yes (need to be updated)		Report	Once	
Market price of kWh (electricity)		X	Energy marketplace	Daily	<a href="http://www.epexspot.com/fr/">http://www.epexspot.com/fr/</a>
Expected calls and type of cargo: <ul style="list-style-type: none"> <li>FAL Forms (date of arrival, date of departure, cargos, dangerous goods...)</li> </ul>	Yes (from VIGIEsip)		72h/24h prior existing XML messages	Daily	<a href="https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/export_demandes">https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/export_demandes</a> .
Expected calls and type of cargo: <ul style="list-style-type: none"> <li>Statistics on calls</li> </ul>	Yes (from VIGIEsip)		Excel spreadsheet	Daily	<a href="https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/export_demandes_facturation">https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/export_demandes_facturation</a> .
Expected calls and type of cargo: <ul style="list-style-type: none"> <li>Characteristics of vessels (specific data on engines must be fetched in Lloyd's registries (IMO number is known))</li> </ul>	Yes (from VIGIEsip)		Vessels also with existing XML messages	Daily	<a href="https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/navires_a_quai">https://bordeaux.vigiesip.eu/vigiesip-webservice-bordeaux/nonauthent/navires_a_quai</a> .
Electricity consumption on port premises (every 10 minutes) <ul style="list-style-type: none"> <li>Lightning</li> <li>Building consumption</li> <li>Reefers consumption</li> </ul>	Yes		Means to collect and send them to be defined	Every 10 minutes	
Characteristics of engines being used during cargo handling		X	Report	Once	
Other fuels consumption		X	Report	Yearly	
Amount of kWh produced	Yes		Through existing models (PVGIS for example)	Yearly	<a href="https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP">https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP</a>

Weather data	Yes (from one weather station)		To be defined	Daily or more often (to be defined depending on the station characteristics)	<a href="https://openweathermap.org/api/">https://openweathermap.org/api/</a>  <a href="https://public.opendatasoft.com/explore/dataset/arome-0025-sp1_sp2/table/?location=-6,46.00538,2&amp;basemap=jawg.streetshttps://2F">https://public.opendatasoft.com/explore/dataset/arome-0025-sp1_sp2/table/?location=-6,46.00538,2&amp;basemap=jawg.streetshttps://2F</a>
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Some data already exists but they need to be updated or collected and some work need to be done before these data can be used in modelling or data analysis. For example, electricity consumption measurements must be precise in terms of representativeness (or measured for each use or aggregated data). These works have presented several pitfalls. As in other work packages, getting real data from ports is a task that involves different agents, permissions and time. Furthermore, it is not always able to be collected. Additionally, some data are still to be collected in order to correctly integrate the energy model. This will be done during the integration phase in WP7.

### ***Scope and boundaries of port activities to model***

We will focus only on the energy consumption and production that directly depends on the port authority of GPMB. Currently, energy consumption and production of 3<sup>rd</sup> parties are out of the scope of the modelling and data analysis exercise since GPMB may not be able to have access to their data due to legal issues. Moreover, there is plenty of actors when loading/unloading ships goods. This clearly presents the scope of primary PIXEL models to be implemented. However, as for D3.4, there is a user scenario that envisions potential transfer to other port agents if they provide their own data. This will be properly analysed at later stages of the project when the deployed models have already been assessed in the pilot trials (in WP7).

## **B.1.2 Port of Monfalcone/SDAG**

### ***Port process description***

In D3.3 and in D3.4 (Use-case and scenarios manual), the Port of Monfalcone, SDAG and INSIEL defined the specific actions of their use case.

The activity that should be modelled for the intermodal use-case is an easier and effective methodology in order to be able to find better logistic solutions referring to the connection system between Port of Monfalcone and SDAG (as a parking area and an intermodal terminal). The result of the lack of communication, in terms of both data and decision-making tools, is the difficulty in the re-routing of the trucks towards SDAG or other parking areas or choosing other means of transport (for example the railway).

What should be provided by the model, is the management of the road traffic to reduce and/or prevent congestions in the port area and so reducing also the environmental impact in the surrounding/urban area of Monfalcone, reducing accident risks and enhancing the management of the parking areas and all other regional infrastructures. These modelling needs are in described in D4.3 in the scenario PoM-GM-1 (that mainly refers to a congestion detection system), SDAG-PM-2, SDAG-PM-2 and SDAG-PM-3 (that refer to the information exchange between SDAG and ASPM and aims at triggering the simulation of the process of parking occupancy based on the information (and thresholds) coming from SDAG’s video camera setup).

## Modelling needs

The modelling needs of ASPM and SDAG are described using users' stories approach. The scenarios are described in D3.4 but in D4.2 there is a particular focus on the modelling needs.

### ASPM

As the **gate access manager**, I want to have **automatic predictions of parking occupancy in the port entry parking area** using the actual parking occupancy, the port gate flows and the vessels scheduling and historical traffic data on a daily basis with "some" hour range so that **truck operators can be notified of congestion of port access and parking availability** / predictions if they overpass certain threshold, as well as other stakeholder (municipality, police), in order to evaluate proper actions to minimize the issue and port-city interference.

ASPM plans to implement a system (based on a video camera) that will count the vehicles entering and exiting the port. Therefore, it will provide a measure of the parking occupancy. Despite advanced, the technology is not still available in ASPM at the conclusion of this document. Furthermore, the video system is capable to monitor a defined area of the access road to the port and send an alarm if the trucks are stuck for a certain period of time. It is planned that the data will be available online. At the same time, the system, in the case the parking area is full (or almost) and the automatic predictions of parking occupancy forecast an increment in traffic flows and parking needs, truck drivers/operators can be notified of it and linked to SDAG in order to reroute their parking destination towards the interport or delay their arrival to the port/parking area. The port cannot oblige a truck to divert its route but only suggest it to stop at SDAG. This information can be shared by PIXEL with SDAG and allow truck drivers to book a parking slot in SDAG facility.

Another aim in PIXEL project is to evaluate the externalities (such as pollution, road consumption and the risks related to slabs traffic) related to specific good flows (slabs) and how intermodality can lower them.

### SDAG

As a **parking area**, I want to **receive automatic alerts of trucks diverted to SDAG from the Port of Monfalcone** and confirm slot availability so that I can check automatically the availability of parking slots and/or reserve + address trucks to the different parking areas.

Furthermore, I want to **have anticipations or predictions of the traffic and congestions in the port/surrounding areas** (through a system that put in communication more stakeholders thanks to SILI platform) so that I can **estimate the number of trucks** coming to SDAG and I can **evaluate the use of all available resources** ports, inland ports and railway) to address the traffic towards other multimodal transport and support the decision making in addressing the trucks towards Monfalcone or other infrastructures.

The objective here is, based on the data provided by other stakeholders, predict possible congestions and so route trucks to SDAG by the other roads available or by the railway.

## Data available and/or to be collected

In order to detect and predict congestion and fulfil the use case a list of required data is listed below.

*Table 23: Data available and/or to be collect in ASPM and SDAG*

Port of Monfalcone				
Data needed	Available	To be collected	Means of transmissions	Frequency

Arrival and Departure time of ships to the port of Monfalcone		X (from PMIS – Port Management Information System)		
Actual and historical traffic data through the port of Monfalcone access gate	Yes (from SILI system)			
N° of free parking lots / Full parking lots	Yes (a video system has to be installed by ASPM to record this data)			
Congestion presence on the road to the port of Monfalcone access gate		Yes (a video system has to be installed by ASPM to record this data)		
Traffic information / congestions along the regional road network		X (from other stakeholders: i.e. Autovie Venete)		
Truck company contact data	Yes (from SILI system)			
Traffic statistics	Yes (from ASPM)			
<b>SDAG</b>				
<b>Data needed</b>	<b>Available</b>	<b>To be collected</b>	<b>Means of transmissions</b>	<b>Frequency</b>
N° of trucks diverted to SDAG		X from Port of Monfalcone	When trucks are leaving the port	When trucks are diverted
Arrival and Departure time of trucks to SDAG		X From Port of Monfalcone	When trucks are leaving the port  When trucks are entering in SDAG / leaving from SDAG: SDAG Access control system	When trucks are diverted to SDAG / are leaving from SDAG
Type of trucks diverted to SDAG (for ex. ADR)	Yes in SDAG (when trucks entering in SDAG there is a video-surveillance and access control system able to read plates and Kemler codes to detect the type of dangerous goods transported)	X (when trucks are diverted to SDAG, we need the information from the Port of Monfalcone)	When the truck is entering in the parking area of SDAG: SDAG Access control system / video surveillance	When trucks are diverted to SDAG / are entering in SDAG
N° of free parking lots / Full parking lots	Yes in SDAG (for the concrete methodology of connecting our system to the pixel platform to get the information		SDAG Access control system at the entrance of the parking area	Real time

	SDAG is consulting the technology supplier)			
N° of free places on the train for trucks diverted to SDAG		X (from other stakeholders)		On demand when the railway is identified as the best solution for diverting the truck
Traffic information / congestions along the regional road network		X (from other stakeholders: i.e. Autovie Venete and FVG Strade)		Daily / For particular peaks of traffic: when needed

### ***Scope and boundaries of port activities to model***

The model will help to understand if a different traffic management has a positive impact on congestions issues, citizens risk on the road and environmental impacts. The main result that will be reached is an effective decision support tool to optimize the re-routing of trucks from the Port towards SDAG or other infrastructures, and so facilitate the staff working in both entities.

The model mentioned above has been split in two sub models, one related to intermodality way of transport applied on slabs traffic between ASPM and Aussa Corno industrial district, the other one related to traffic and parking inside port premises and the possible rerouting to SDAG. We are going to call the first one “intermodality sub model” and the second one “traffic sub model”.

### **B.1.3 Port of Piraeus**

#### ***Port process description***

The process that will be modelled is the noise and air emissions from the container terminal and passenger /cruise terminal activities respectively. The PPA port complex is the nation’s largest passenger and cruise hub and includes its busiest container port complex. As described in D4.3 PPA wants to “*establish an air quality improvement plan in order to monitor the pollution emitted within their areas of operations*”. The scenario PPA-EM-1 give all the information about air pollution is addressed in PIXEL context. PPA also want to address the noise pollution issue. This is described in the scenario PPA-EM-2 in D3.4. In this research effort, the noise distribution at the port of Piraeus needs to be addressed via modelling the following activities:

- Co-evaluate in combination with the results of LAeq indicator measurements in order to have adequate data for noise mapping in the residential area.
- Estimate the noise level impact of the Container Terminal in the residential nearby area.

The following issue are not directly related to modelling, but they may be addressed in parallel.

- Determination of the main sources that dominate the noise emitted by ships during port condition.
- Overview of the possibilities to attenuate the noise sources with technical solutions.
- Assess the key noise source in the area.
- Determine the noise levels per activity fluctuation during the period of study.
- Estimate the influence of the air emissions related with the port activities (cruise and passenger terminals) at the city.

- Have predictions for the effect at the city (emissions alarm mapping) by the air emissions associated with the cruise and passenger Terminal.

According to PPA, the pollution models have to be able to get all environmental related information accessing the PIXEL hub and generate a result, which will be stored as a facility from the Operational Tools. The result may depend on:

- space: pollution across a geographical area. The result may be represented in a map or GIS,
- time: pollution throughout one day on a per hour basis. The result may be represented as a bar chart (each hour). Furthermore, two graphs may be overlapped in order to show one specific aspect of the pollution vs the total amount.

### ***Modelling needs***

As an **environmental operator**, I want to have **predictions for the effect at the city** (emission alarm mapping) by the **air emissions with the Cruise and passenger** so that the port will develop air pollution dissemination models based on evaluation of air quality measurement and meteorological data.

Cruise and passengers' ships, and the large amount of associated bus and taxi traffic that transport cruise/coastal shipping passengers to and from tourist destinations and islands in the area, are one of the most problematic pollution sources by members of the PPA community.

As an **environmental operator**, I want to have an accurate **estimate the noise level impact of the Container Terminal in the residential nearby area** so that I can **establish a permanent noise monitoring** network with suitable sensors for 24/7 measurements of Lden indicator in the Container Terminal area.

### ***Data available and/or to be collected***

The availability of data for the modelling needs are listed in Table 4 and consist of three main categories:

#### 1. External data sources:

##### 1. Meteorological data form:

- <http://www.meteo.gr/index-en.cfm>
- <https://opendata.ellak.gr/2018/02/06/anichta-meteorologika-dedomena-stin-ellada/>

##### 2. AIS real time vessel traffic monitoring data (sources: <https://www.marinetraffic.com/>)

##### 3. Public transport data from:

- [http://www.stasy.gr/index.php?id=1&no\\_cache=1&L=1](http://www.stasy.gr/index.php?id=1&no_cache=1&L=1)
- <http://www.oasa.gr/?lang=en>

#### 2. PPA IT systems:

From the ORAMA ERP and N4 EXPRESS PPA system the following data will become available:

- Input data of containers, cargo and Ro-Ro;
- Output data of containers, cargo and Ro-Ro;
- Cruise arrivals/departures;
- Cruise planning per date;
- All domestic passengers per ship and month;
- All vehicles (except commercials) per ship and month;

- Ships arrivals and departures;

3. PPA field measurements:

- Air quality data:

An Air quality station has been installed and is under full operation in 24/7 mode. The monitoring indicators are: -CO, BTEX, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>10</sub> and meteorological data. The monitoring program is been implemented in collaboration with the National Technical University of Athens since 2009. The data are available in excel form (24/7 per month) archives and in annually evaluation report.

- Noise data:

LAeq indicator, derived from 2 set of measurements per year in 25 spots around the port.

Table 24: Data available and/or to be collect in PPA

Port of Piraeus				
Data needed	Available	To be collected	Means of transmissions	Frequency
Input data of containers cargo and Ro-Ro	Yes		N4/EXPRESSJ/CARGO_IN.XLS	Following month
Output data of containers cargo and Ro-Ro	Yes		N4/EXPRESSJ/CARGO_OUT.XLS	Following month
Cruise arrivals/departures	Yes		ORAMA ERP	Following month
Cruise planning per date	Yes		ORAMA ERP	Following year(s)
All domestic passengers per ship and month	Yes		ORAMA ERP	Following month
All vehicles (except commercials) per ship and month.	Yes		ORAMA ERP	Following month
Ships arrivals/departures	Yes		ORAMA ERP	Following month
Ships arrivals/departures	Yes		ORAMA ERP	Near real time
NO <sub>x</sub> , SO <sub>2</sub> , CO, O <sub>3</sub> , PM <sub>10</sub> , BTEX	Yes	Yes	excel form (24/7 per month) archives and in annually evaluation report	Semi-annual and annual reports
LAeq indicator	Yes	Yes	Word files	2 set of measurements per year in 25 spots around the port.
Weather data	Yes	Yes	Real time by external source	Real time <a href="https://opendata.ellak.gr/2018/02/06/anichta-meteorologika-dedomena-stin-ellada/">https://opendata.ellak.gr/2018/02/06/anichta-meteorologika-dedomena-stin-ellada/</a>
Vessel traffic monitoring	Yes	Yes	Real time by external source	Real time/ <a href="https://www.marinetraffic.com/">https://www.marinetraffic.com/</a>
Public transport data	Yes	Yes	Real time by external source/open	Real time

Some data could be missing due to a lack of the tools. PPA will try to fill them through PIXEL:



- Noise levels: there is no permanent network operated. The noise measurements are available in semi-annually base.
- Air quality: there is a permanent air quality measurement station that is operated in Passenger Terminal area. There is need for enhancement the network with a station covering the cruise terminal.

### *Scope and boundaries of port activities to model*

The scope of the PPA model is to create a noise model and a pollution model with the establishment of baseline levels for both models that through the PIXEL Hub and the PIXEL Dashboard will run generic and custom simulations for noise and pollution parameters.

#### **B.1.4 Port of Thessaloniki**

##### ***Port process description***

As described in D.3.4, THPA “is very close to the city centre. During the last five years’ business activities have been transferred to the surrounding area of the Port. A number of luxury hotels and new business centres have been constructed just outside the port area, thus being directly influenced by normal daily port activities. As consequence they face the problem of dust and noise due to their proximity to the port, although the port is offering a great view to their customers and employees.”. That is why air quality and noise pollution are considered as a top priority by THPA. THPA expects to have an estimation and visualization of the quantity of the emissions caused, as well as its dispersion in the air according to weather conditions and, if possible, the contribution of the port to the overall pollution of the city. In that way, ThPA personnel will be able to make scientifically based decisions on everyday operations, such as personnel and machinery allocation, reduce number of operations, etc. The scenario ThPA-EM-1 is related with air pollution while ThPA-EM-2 with noise pollution.

##### ***Modelling needs***

As **environmental manager**, I want to **estimate the air pollution impact of bulk cargo operations** to the city due to specific/bad forecasted weather conditions, for the next day so that we can **make decisions to decrease the impact**.

Also, due to the unique characteristics of handling bulk cargo, Environmental Operator Personnel need to have an estimation of the air and noise pollution impact of operations (truck flows, loading / unloading – operating machinery) to the city because of specific/bad forecasted weather conditions, so that they can make decisions in order to decrease the impact (sprinkling, reduce number of operations, etc.). The most prevalent pollutant to take into consideration is the PM<sub>10</sub> particles. In order to visualize the quantity and parts of the city that are affected, a dispersion map is required.

As **environmental manager**, I want to **estimate the air pollution impact of handling cargo** to the city due to specific/bad forecasted weather conditions, for the next day so that I can **have a clear picture of the quantity that adds to the pollution of the city**.

Environmental Operator Personnel need to have an estimation of the air and noise pollution impact of handling cargo (truck flows, loading / unloading – operating machinery) to the city, due to specific/bad forecasted weather conditions, on an hourly / daily basis, so that they have a clear picture of the quantity that adds to the pollution of the city, as well as the parts of the city that are affected by port operations. In order to visualize the quantity and parts of the city that are affected, a dispersion map is required.

As **environmental manager**, I want to **estimate the amount of noise from operating machinery for handling cargo** (loading / unloading) so that I can **have a clear picture of the quantity that adds to the noise of the city**.

The outcome (model) should be a combination of all the above. The expected precision in terms of space, is in meters or kilometres of the distance between the main field of port operations and the city. The expected precision in terms of time is, if possible, on an hourly / daily basis.

### ***Data available and/or to be collected***

The minimum sets of data we need in order to provide useful answers to the modelling objective, are:

- Number of trucks entering daily ThPA’s premises, dwell time, engine types, fuel consumption, emissions / noise.
- Number and type of mechanical equipment to unload/load truck; Dwell time, engine types, fuel consumption, emissions / noise.
- Spatial data regarding berthing areas (areas of loading/unloading), ThPA’s premises, position of sensors.
- Meteorological data; wind (velocity/direction), temperature, rain, relative humidity.
- PM10 emissions from machinery usage, truck flows<sup>19</sup>.

ThPA provides spatial data regarding berthing areas (areas of loading/unloading), ThPA’s premises and position of sensors.

As for meteorological data, ThPA will provide data from its station inside the port’s premises, on temperature, relative humidity (%), wind direction and velocity. Meteorological data can also be acquired through public databases (Municipality of Thessaloniki, etc.) of nearby meteorological stations.

Pollution data on various pollutants (SO<sub>2</sub>, NO<sub>2</sub>, CO, PM<sub>10</sub>, PM<sub>2.5</sub>) will be provided by ThPA from its meteorological station. Data is gathered 24x7. Also, data from an extra “echo PM” sampler, gathering data on heavy metals in the air, will be provided. Furthermore, pollution data on PM<sub>10</sub> & PM<sub>2.5</sub> particles can be collected when needed, through targeted measurements with a portable sensor. Data can also be acquired through public databases (Municipality of Thessaloniki, etc.) of nearby stations.

Apart from the aforementioned sets of data, ThPA has at its disposal data concerning sea water quality, collected every six months with a mobile sampler, from four prefixed points. Moreover, data on electrical consumption are available, for 9 electric substations (mid-voltage). Not all relevant data, only a subset: consumption in KWh, cosine, financial data. Data on fuel quantities are also available.

Finally, no data on pollution or noise deriving from ship’s engines are available but based on the type of ship (ThPA statistics, official classification by IMO), time that remains in the port and horsepower, conclusions can be extracted.

*Table 25: Data available and/or to be collect in THPA*

<b>Port of Thessaloniki</b>				
<b>Data needed</b>	<b>Available</b>	<b>To be collected</b>	<b>Means of transmissions</b>	<b>Frequency</b>
FAL Forms	Yes			
Entry / exit of trucks (RFID tags)	Yes		Stored in relational database (MySQL)	Real-time.
Wind direction/speed	Yes		Sensor inside ThPA, on GC#3: stored in relational database (SQL Server)	Real-time
Wind direction/speed, temperature, relative humidity (%)	Yes		Sensor inside ThPA (rooftop of TY building). Export,	

<sup>19</sup> <https://www.softnoise.com/pd/sourcedb.html>

			static files in TXT (needs transformation)	
Electricity consumption #1	Yes		Manual data entry (from monthly electricity bills), for 9 electric substations (mid-voltage). Not all relevant data, only a subset: consumption in KWh, cosine, financial data. Stored in relational database (MySQL).	Monthly
Spatial data	Yes		.dxf files, .shp files, a (hand-crafted) KMZ (GoogleEarth) with “points-of-interest” inside THPA premises (ie location of met stations)	
Pollution data #1: PM10 & PM2,5	Yes		From TSI8530 (portable handheld PM analyzer) used inside ThPA. Data downloaded locally in XLSX format	
Pollution data #2: Various pollutants (SO2, NO2, CO, PM10, PM2,5) from met station inside ThPA	Yes		Sent (via SIM card) real-time to web logger airmonitors.net (web interface & export, API option mentioned on website). Also installed, a “TECORA echo PM” sampler, 10mins every hour, data gathered once a month, heavy metals in air (mean monthly value)	Gathered 24x7,
Sea water quality	Yes			Every six months sampling of four points, mobile sampler, manual data entry of results
Primary weather data from NMS stations (Athens...)		Yes. Open data.		<a href="https://opendata.elak.gr/2018/02/06/anichta-meteorologika-dedomena-stin-ellada/">https://opendata.elak.gr/2018/02/06/anichta-meteorologika-dedomena-stin-ellada/</a>
Thessaloniki's municipality open data		Yes. Open data.		<a href="https://opendata.thessaloniki.gr/el/search/type/dataset">https://opendata.thessaloniki.gr/el/search/type/dataset</a>
Weather data of stations. Summary per months.		Yes. Open data.		<a href="http://meteosearch.meteo.gr/data/kerkyra/2018-10.txt">http://meteosearch.meteo.gr/data/kerkyra/2018-10.txt</a>
Thessaloniki's municipality open data on meteo		Yes. Open data.		

Pollution data #3 (from City’s sensors, outside ThPA)		Yes. Open data.	Static files for download in CSV, as far back as 1984. No geo-information	<a href="http://www.ypeka.gr/Default.aspx?tabid=495&amp;language=el-GR">http://www.ypeka.gr/Default.aspx?tabid=495&amp;language=el-GR</a>
Electricity consumption #2		Yes. Open data.	Option to download locally in XLS, CSV, PDF. No API for automatic download/import mentioned on site, though.	To enter with THPA account. DEDDIE (ΔΕΔΔΗΕ) is the Greek State grid owner. Real IoT, sensors on electricity meter, consumption every 15’ (per substation), 9 substations.
Thessaloniki’s city atmospheric pollution. SO <sub>2</sub> , PM <sub>10</sub> , PM <sub>2,5</sub> , NO, CO, NO <sub>2</sub> , O <sub>3</sub> ...		Yes. Open data.	.xlsx format. Archive from 1989 to 2016. DCAT compatibility. Also available in RDF and JSON.	<a href="https://opendata.thessaloniki.gr/el/search/type/dataset">https://opendata.thessaloniki.gr/el/search/type/dataset</a>

### *Scope and boundaries of port activities to model*

Due to the port’s size and proximity to the city, the aim is to visualize the amount of pollution caused by port operations, primarily by trucks entering/exiting the port premises and the associated machinery used, as well as the areas of the city that are affected by it. The scope is to fuse the available information to have an overall picture on congestion hours and pollution created, so as to achieve optimum allocation of the equipment, trucks and personnel, thus decreasing the Port’s environmental impact on the city.

## **B.2 Link with WP5: Environmental impacts measurement for ports activities**

According to the Port Emission Toolkit (GloMEEP and IAPH, 2018.) emission inventories “catalogue the various port-related emissions sources and their activities, translate those activities into energy consumption levels and then translate energy consumption into emissions. They provide insight on activities and related emissions of the various source categories, within defined geographical, operational and temporal domains”.

In order to set the stage for deploying the Port Environmental Index (PEI) an inventory of emissions will be built for each of the ports based on the data they will provided for the Port Activity Scenario (PAS). This would need the provision of emissions forecasts based on energy consumption forecasts. The prediction would need the provision of ports to adapt their operational parameters in order to decrease their impact on the environment.

The specific type of emission inventories built will depend on the identification of the significant environmental aspects by the ports. However, based on the current understanding of the problem the following emission inventories will likely have be built for the ports:

- emissions to the atmosphere,
- emissions to the seawater,
- noise emissions,
- production of waste,
- light emissions.

Except for light emissions pollution, these items are identified in the top 10 environmental priorities of the ports in 2018 (ESPO environmental Report of 2018). Regarding the specific inputs for PEI, these will be based on the KPIs which will be identified for each significant environmental aspect.

## B.2.1 Indicators

### *Emissions to the atmosphere*

For the emissions to the atmosphere a list of potential eKPIs could look like this:

- sulphur dioxide (SO<sub>2</sub>) emissions,
- particulate matter (PM) emissions
- nitrogen oxides (NO<sub>2</sub>) emissions,
- greenhouse gasses (GHG) emissions,
- emissions of volatile organic compounds (VOC),
- carbon monoxide emissions (CO).

This list of eKPIs will be fully described in WP5 and the associated deliverables.

In ports there can be found both stationary sources (e.g. industrial boilers) and mobile sources (heavy and light-duty vehicles, vessel, etc.). All these sources are mostly point sources and usually are modelled as such in case there is a modest number of point sources. However, since in ports there are many point sources distributed over an area, we suggest modelling the emissions in the aggregate, for the whole port. The emissions in the aggregate for the whole ports will have to be expressed per unit cargo. Since the emissions will be expressed in the aggregate for the whole port a method has to be established to allocate the emissions expressed in the aggregate to the cargo.

For example, if a port handles 100.000 TEU and 50.000 tonnes of bulk cargo per year and it emits 1000 tonnes of GHGs per year the question is how to allocate the 1.000 t of GHG emissions between TEU and bulk cargo. This have to be done in order to properly compare ports with each other. Indeed, regarding PEI all the emissions will have to be expressed per unit cargo. Absolute values are not representative since bigger ports will have higher emissions because they handle more cargo. Therefore, in our opinion the best appropriate approach is to express the data per unit cargo.

### *Emissions to water*

For emissions to the sea water, the first need is to know how much wastewater is emitted to the marine environment. This inventory can be done by the following listed sources:

- Port authority (sanitation or rainwater networks),
- Terminal operators (industrial process, shipyard or careening area, ...),
- Ships (ballast, grey and black waters), etc.

But this simple way of census doesn't take care of the indirect effects of harbour activities on water quality, like the sediment particle resuspension dues to vessels navigation. On this point, GPMB in the Gironde XL 3D (Laborie, 2013 and 2018, Huybrechts) project work on the implementation of a 3D numerical model able to reproduce the hydrodynamic, salinity, sediment transport and morphodynamics of the Gironde estuary and integrating weather conditions such as wind and storm surges. The developed numerical models are the subject of a complete project (with EU support<sup>20</sup>) with complex numerical methods and requiring important computing resources (supercomputer use). This type of implementation and usage complexity does not seem to be suitable for the PIXEL project. Therefore, developing a model of dispersion of pollutants in PIXEL context seems difficult. Moreover, this kind of model required a lot of data that PIXEL's ports are not able to gather. Despite the fact that this kind of dispersion model in water will not be addressed, wastewater emission will be quantified for PEI.

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<sup>20</sup> <https://www.portdufutur.fr/gironde-xl>

For all the effluents listed, these potential KPIs linked to water quality can be used:

- Total water rejection in sea per activities (m<sup>3</sup>)
- Suspended matter or turbidity (for each one)
- Salinity
- Hydrocarbons concentrations
- E. coli or fecal coliforms contamination
- Heavy metal concentrations
- Dissolved nutrients (C, N and P)

### ***Noise emissions***

Noise emission will be based both on the on-site measurements and on the estimations of the noise levels based on the reported port activities. Portable decibel meters exist which are not very expensive, and ports are usually equipped with those. This means that several noise measurements can be carried out at different time intervals and different sampling points.

### ***Production of waste***

Waste production will be estimated based on the data obtained from the waste collectors as well as in-house collected data on separate waste collection. Effort will be made to normalize all data per unit cargo.

## **B.2.2 Geographical emission inventory**

Another important issue is to define the geographical and operational domain of the emission inventory. There is a large array of geographical layouts and features of ports and no single geographical definition of the port's domain exists. A commonly applied geographical domain is the port administrative boundary and we will thus use this geographical domain when estimating emissions. Everything that is inside the port's administrative boundary will be considered as an emissions source whereas everything outside the boundary will not be considered an emission source of the port.

It must be pointed out that when modelling port-city interaction with respect to translating emissions to impacts to the surrounding environment or predicting the concentration of a certain pollutant once it enters the environment, the geographical domain will have to be extended. This will be done in the second step by modelling pollution dispersion which will use emission inventories as an input.

Regarding the level of detail ideally, we would have to conduct a comprehensive inventory of emissions for the four ports involved. Comprehensive emissions inventories are considered the gold standard/best practice since they are based on detailed emissions estimating methods. Obviously, such an approach is much more complex than using screening methods but the uncertainty regarding outcomes is much lower. They are dependent on significant amounts of data which must be generated by the ports and also the approach limits the use of proxy data. According to the current knowledge for certain environmental aspects the data resolution is granular enough to allow for a comprehensive assessment to be carried out whereas for other aspects some of the data will have to be derived from proxy data or even scaled using data from other ports.

## **B.2.3 Inputs needed for each sources of emissions**

For air and seawater pollution, the following inputs will have to be identified to develop activity-based inventories for air and seawater pollution:

- **Data on emission sources.** This is to detail the characteristics of each emissions sources.
  - Air Pollution: Size or rating of the engine, type of fuel, engine technology, equipment specification, etc.
  - Seawater pollution: Type of effluent (wastewater, industrial process water, rain water discharge, treated water discharge...)
  - Noise pollution: Localisation, type, geographic information, ...
- **Port activity and operational.** We need this data in order to detail activity in terms of hours of operation, number of calls, etc.
- **Data on physicochemical characteristics of effluent and pollutants:** flow, density, pollutant concentration, bacteriological contamination, ...
- **Emissions factors or emission data test for port activities,** what is the estimate quantity of effluent or pollutants released to the marine environment and/or atmosphere. These data can be estimated or measured directly (flow meters) before the release to the sea or atmosphere.

### B.2.4 Pollutant dispersion models and link with the PEI

The environmental impact is strictly speaking not only a function of the environmental performance of a port but of other parameters as well over which the port does not have any control. An example of which is atmospheric stability. Thus, when environmental performance of a port is assessed it must be decoupled from other factors which are not influenced by the ports. Therefore, the eKPI of interest which will be used are only the ones that are related to the emissions from the port's area and will not include indicators of the quality of the port's natural environment.

PEI will use the data on emissions related to different eKPI which will be established once the significant environmental aspects are properly formalized and identified and will normalize the data, weigh them and integrate them into a single composite indicator.

Pollutant dispersion models will not be integrated into the PEI but will allow ports to better understand how pollutants related to their activity impact the City. Indeed, pollution models are more focus on the quality issue that is not directly addressed by PEI.

## B.3 WP6: PIXEL model's integration inside the PIXEL Platform

PIXEL can be seen both as a technological and environmental solution; the former dimension is mainly covered by WP6 activities whereas the latter one by WP5 activities. Obviously, there is some sort of overlap between them and this is the aim in PIXEL: otherwise we may end up with two different systems without giving the environmental aspect the place it deserves for high level decision support systems.

WP4 comes into scene in order to support and provide a grounding level for the previous WPs, as already depicted in the core document. In this appendix we describe the relationship with WP6 and how both WPs interact and need each other.

WP6 is responsible for drawing an overall architecture that encompasses all necessary components and, therefore, WP4 components. Relevant WP6 components are:

- Data acquisition layer: it provides a means of collecting all heterogeneous data sources and sending them to the PIXEL hub
- Information hub: it represents a communication hub where all data and basic platform services can be consumed

- **Dashboard:** it mainly represents the User Interface (UI) with the port operators, with some notification and Business Intelligence (BI) features. As frontend, it may potentially integrate other high-level applications.
- **Operational tools:** they represent a set of (high level) tools to properly analyse the status of the port through simulation and analysis in order to help port operators making better decision in planning and management.

The models developed in WP4 can be considered as basic platforms services incorporated inside the PIXEL framework. Such services (models) consume in fact part of the data available in the Information Hub as input and generate process optimization outputs providing added value that can be later consumed by higher level tools. The operational tools represent direct consumers of such services; one of the tools consists of a simulation engine in charge of simulating environments with the help of WP4 models. This will be better described in the following subsections.

### B.3.1 Data management

The data needed for the models comes from heterogeneous sources and in various formats. As the models are focused on efficient representation of tasks to simulate, it is important to relieve them from extra burden of processing input data. Therefore, the data acquisition layer, as part of WP6, is in charge of connecting any potential data source to the PIXEL hub, the entry point for WP4 models and any other service that intends to consume data. For example, this data acquisition layer will connect PLCs, IoT sensors, virtual sensors to the hub in a proper way, accomplishing several tasks:

- **Authentication:** the data source identity must be checked before being accepted in order to avoid data attacks. The communication with the hub must be secured.
- **Verification:** the generated data must be verified to a certain extent in order to pre-check that obtained values are coherent before sending them to the PIXEL hub. The data in the hub must be reliable.
- **Filtering and aggregation:** all generated data does not need to be processed and sent to the PIXEL hub, but sometimes a small subset of it. This specially makes sense when working with IoT gateways, which may aggregate data and send a summary result to the upper layers. The data in the hub must be concise and non-redundant.
- **Sampling:** Every data source generates information with a certain periodicity. Configuring the sample rate for each data source correctly is important and determines network and content traffic.

### B.3.2 Data warehouse

For each model developed in WP4 there is a specific list of input data items that are available. Though such availability may consist of directly accessing the involved sensor, database, etc., it is more convenient to access all necessary input data through the PIXEL information hub for various reasons:

- **Single entry point and discovery:** it provides independency from any port implementation as there is no need for the models to store a list of available data. Note that each port may have different data available and it is more practical to configure it once in the hub than configuring everything in each model. Therefore, each model will only have to invoke the discovery service available in the hub in order to look for the necessary data.
- **Pre-processing features:** Any model (or basic service) may access confidently the required data available in the hub without the need for performing extra processing. Any relevant low-level data process should be performed by the data acquisition layer.
- **Common format:** the list of available data items is presented in a common data format and interface, as well as the data itself from each data source.

Apart from accessing the data through the PIXEL hub, each model may also require its own database for internal usage as well to provide results.



### B.3.4 Data manipulation

Every model developed have its own input and output data. At WP4 level, there is a global intent of homogenizing the way models are described and therefore provide a basic means of inserting data and getting data. This will allow interoperability among models to some extent.

At WP6 level, one relevant challenge consists in encapsulating models in form of services MaaS (Models as a Service) in order to facilitate the integration at platform level and provide a clear open interface (e.g. Swagger). This will allow better adoption in other ports.

### B.3.5 PIXEL Dashboard

The PIXEL Dashboard will be the user interface (UI) of port operators to manage all PIXEL services and components. As a subcomponent of it, the operational tools will be in charge of making use of the models generated in WP4. Models are created according to a type, identified in WP4: energy, transport, pollution and city. Other models could be potentially added but PIXEL is currently limited to this scope.

- Models can have four states: running, finished, stopped and error. Note that models simulate a specific complex scenario and therefore it may take some time until the results are available.
- Depending on their status, some actions can be performed to the models: stop, edit, delete, view results, etc.

Several interactions between the models and the operational tools have been identified:

- For each model type, a UI template must be defined to create the model, allowing to configure activities, input and output parameters
- For each model type, a way of visually presenting results should also be defined. Probably each model will deliver output data in a common format (e.g. JSON), but this has to be converted into a graphical result (e.g. bar chart)

## B.4 WP7: Implementation and test of PIXEL models

As described in the GA, one objective of the WP7 is to apply “*properly the models described in WP4*” and “*connect to the different data sources in the ports, according to the approach developed in previous WPs*”. This means that the real implementation, test and validation of PIXEL models will be done in WP7 scope using all methodologies introduced in the present document. Thus, in WP7 PIXEL models will be tested and validated as follows (readers can find more inputs about the test and validation methodology in deliverable 7.1 “Integration Report V1”):

- Energy models combined with the port activity model will be tested using real inputs data of the port of Bordeaux and results will be compared to bills or shown to the energy manager of the port to validate the order of magnitude. Readers should have in mind, that the full methodology to model energy consumption due to un/loading vessels has been built with a direct collaboration of port operators and are based on classical modelling approach.

After test and validation, predictive algorithms and PIXEL models will be used to “*implement an optimisation strategy of the production and consumption of energy*”. Our objective will be to predict the energy demands and peaks, the consumption associated with a port activity. Thus, PIXEL models will be used to help GPMB to make a decision about the choice to invest or not in energy self-production.

- Transport models will be tested and validated in ASPM and SDAG based on the expertise of the port operators and managers. These models have been designed using expert knowledge but must be parameterised with real values and conditions. The model parameterisation will be done in WP7 and if some adjustments are needed, they will be done as part of WP7. They will be used in order to “*increase*”

*the use of rail and plan collateral services that can facilitate a sustainable intermodal transport”, “to reduce bottleneck and random congestion”.*

- Air and noise dispersion models will be applied in WP7 in THPA and PPA. These models are based on state-of-the-art approach that have been already validated and tested. In WP7 the main objectives will be to connect these modes with the different data sources in ports in order to provide specific results. These results will be used to give ports new information about how their activities impact the city and what are their contributions to air and noise pollution of the city.

# Appendix C – State of the art

## C.1 State of the art – Environmental management models

An environmental management system (EMS) is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency. It is a framework that helps an organization achieve its environmental goals through consistent review, evaluation, and improvement of its environmental performance (EPA, 2017). Such systems are commonly based on standards such as ISO: 14001 and EMAS. The intended outcomes of an environmental management system include (ISO, 2015):

- enhancement of environmental performance;
- fulfilment of compliance obligations;
- and achievement of environmental objectives.

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). ISO: 14001 specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance.

EMAS – Eco-Management and Audit Scheme (EMAS, 2017) is a premium management instrument developed by the European Commission as a step-up to ISO: 14001 for companies and other organisations to evaluate, report, and improve their environmental performance.

Regarding the ports industry, the modern environmental management systems like EcoPorts and Green Marine and incentive programs like ESPO, ESI etc. are described at chapter 4 of *PIXEL Deliverable No 3.1 – Stakeholders and market analysis report*.

An environmental management model aims to model the environmental management of an organization by allowing the calculation of the environmental impacts of its operations. Such a model can be a part of an EMS.

The port operations may include the following as explained in the “*Manual of Best Management Practices for Port Operations and Model Environmental Management System*” (Fisher, et al., 2015):

- Dry bulk storage & handling.
- Liquid bulk storage & transfer (loading/unloading).
- Non-bulk chemical storage & handling.
- Port cargo handling equipment & rail/truck operations powered by diesel engines.
- Vehicle & equipment fuelling.
- Port authority oversight of tenant activities through lease agreements.
- Management of hazardous and non-hazardous waste generated by port/tenant activities.
- General operations that can impact neighbouring areas: noise, light, odour, trash, dust.
- Building & grounds maintenance.

Note that cargoes may include coal, asphalt, salt, cement, grain, steel, machinery, passenger/auto ferry service, etc. Port Activities can be divided into two basic categories as shown by (Paipais, 1999):

- Development Activities – May be on land and at the land-water interface and concern construction works with the associated transfer stations for construction material and possibly demolition works a debris.

- Operational Activities – They occur both at the land-water interface and on-land.

Although PIXEL concerns mainly the Operation Activities, the development activities are also considered briefly here for the completeness of the presentation.

*Table 26: Port development activities (Paipais, 1999)*

Port Development Activities	Potential Impacted Medium				
	Surface water quality	Groundwater quality	Aquatic Habitats	Air quality	Humans (health & interests)
Dredging	+	+	+	+	+
Unconfined open-water disposal	+		+		
Disposal on land	+	+	+	+	+
Land reclamation			+	+	+
Construction of waterside structures	+	+	+		+
Establishing of new buildings/structures on land	+	+	+	+	+

*Table 27: Port operational activities (Paipais, 1999)*

Operational Port Activity	Potential Impacted Medium					
	Water	Air	Sediment	Soil	Habitats	Humans (health & interests)
1. Cargo Handling and storage						
Dry bulk - organic	+	+	+	+	+	+
Dry bulk - ores and minerals	+	+	+	+	+	+
Liquid bulk - organic	+	+	+		+	+
Liquid bulk - minerals	+	+	+		+	+
Timber	+				+	+
Refrigerated goods	+	+				
Fish landing and processing	+	+				+
2. Workshop and yard activities						
Vehicle and equipment maintenance (including painting and stripping)	+	+		+		+
Vehicle and equipment washing	+			+		
Handling and storage of chemicals (non-bulk)	+	+		+		+
3. Ship breaking	+	+			+	+

4. Vessel and equipment repair and maintenance (including stripping and painting)	+	+				
5. Fuelling and bunkering (on-land & at land-water interface)	+			+		
6. Building and open area maintenance	+			+		
7. Vehicles storage and transport in car terminals	+					
8. Ship and shore solid waste collection	+	+		+	+	+
9. Public access/areas and recreation in harbour waters and shore	+		+		+	
10. Shipping						
Ship movement		+				+
Ship discharge - ballast water	+		+		+	
Ship discharge - sewage	+		+			+
Ship discharge - bilge water	+				+	+
11. Transshipment						
Containers						+
Ro-Ro						+
Passenger/Ferry						+
12. Maintenance dredging and disposal	+		+	+	+	+

As it can be seen in the above table a variety of mediums is impacted by the port’s operations (in the framework of PIXEL, the ports’ operations as regarded as small scale supply chains).

According to (Krajewski, et al., 2013), one key supply chain sustainability challenge is Environmental responsibility (the other two being Financial and Social responsibility). Environmental responsibility can be achieved through *Reverse Logistics* (the process of planning, implementing and controlling the efficient and cost-effective flow of products, material and information from the point of consumption back to the point of origin for returns, repair, remanufactured or recycling) and *Efficiency* of the operations. Indeed, supply chains involve the flow of goods from their origination to their destination. As such, they consume energy which not only is expensive from a business perspective, but it can also have negative effects on the environment as seen from the above tables.

Current research on supply chains energy efficiency is mostly focused on transportation efficiency (Salesman Problem). Although the transportation model of PIXEL aims to increase the efficiency of this kind of operations (by evaluating and reducing port-oriented traffic and its subsequent environmental impact), most of the ports’ operations are taking place in a limited space and different means of efficiency optimization is required. Such efficiency optimization will reduce the energy consumption of the ports. According to McKinsey (Chu, et al.,

2018) the way forward is automation of ports with careful planning and management. This could lead to decrease of operating expenses by 25 to 55 percent. The way forward to achieving the desired automation is consisted of the following principles:

- Automation-ready capabilities building.
- Strong project-governance and communication plan setup and execution of the plan with discipline.
- Road map definition to realize value from automation.
- Technology ecosystem building and continually refreshing.
- External data incorporation into the automation system.

Currently only large ports have achieved large degrees of automation: Rotterdam, Singapore, Qingdao are the most notable examples, mainly regarding their container terminals where Gantry Cranes, Rail Mounted Cranes and automated guided vehicles control the flow of containers in a fully automated way, reducing downtimes.

Cited (Chu, et al., 2018) barriers towards desired automation include:

- Shortage of talent for specialized technical positions.
- Poor data quality regarding the operations.
- Siloed operations.
- Exceptions handling.

By offering solutions that will improve data quality, integrate port operations from end to end and assist in exception handling, ports can increase their efficiency and decrease their energy demands and their environmental impact.

## C.2 State of the art – Energy demand model

Globally, models that can predict energy consumption are divided into two types of approach, on the one hand the "statistical models", on the other hand the "mechanistic models".

Statistical models typically fall within the analysis of time series, multifactorial regression or neuron networks (for a general introduction to Machine Learning approaches for energies consumptions, see (Fallah 2018)'s review). The underlying mechanics is to extract patterns from energy consumption historical dataset (and possibly contextual variables), in order to infer future consumption. Despite their great qualities and usefulness, statistical models do not seem to be appropriate for constituting the core of the consumption module in PIXEL given the constraints identified (data availability is an identified problem):

- First, because no historical dataset is available for model initialisation, which is required even for a reinforcement learning algorithm.
- Second, in the context of a significant evolution of port activities (evolution of equipment, traffic or other), the accuracy output of the model is likely to collapse. To prevent that, expertise about statistical model deployment, control and update would be required in port's staff. But this is in contradiction with the specified constraints to easily deploy the PIXEL platform in small and medium ports and allow operators to appropriate it.

Mechanical models are based on deterministic analysis of the physical characteristics of the system in operation. Knowing the mechanisms involved during the modelled process, a deterministic calculation can predict consumption. The approach used in PIXEL is quite similar to the one proposed by (Serno 2016). At each transition of goods within the port, a list of handling operations is associated. Each of these operations points to a machine for which characteristics are known. Knowing the machine nominal consumption and throughput, as well as the cargo volume, we can estimate operation energy cost. By integrating across time, the consumption of all the operations related to the cargoes transition in port, we obtain the total consumption as a time series.

Given the constraints identified, such an approach seems to be more appropriate for energy consumption modelling than a statistical approach:

- First because there is no mismatch with listed constraints.
- Second because this approach is based on describing daily activities that port's operators know well. This may facilitate PIXEL employment by its end users.

In PIXEL, we currently focus on energy consumptions due to cargoes handling for transit into ports. For support consumptions forecasting (e.g. building and light), it may be more relevant to use a separate model. Academic reviews as (Li 2015) provide comparison of several models dedicated to buildings' consumption, as BREDEM (British), PRISH & HBM (United States), CHREM & CREE (Canadian), NKFM (Finland) and HM (Belgium). The second phase of the study should point relevant information to enable us to choose a convenient model. As an example, knowing the most common use about turn on the berths' lights (automatic with fixed hour, brightness detection or manual).

## C.3 State of the art – Energy production model

### C.3.1 Literature review

#### Direct and indirect approaches

There are two main approaches for photovoltaic power plant production's prediction (see Figure 16).

The indirect approach uses an irradiance value, injected as an input for electrical production prediction. The irradiance can be predicted through weather data, satellite image, sky image analysis (cloud tracking). It can also be supposed similar to the average of recorded values for similar period and site. The irradiance value is then injected as an input for the second stage of the calculation, that can be a mechanical model or a statistical model (if an electrical production's historical dataset is available).

If a mechanical model is expected, some contextual information may have to be considered for choosing the optimal model. As an example, the Sandia model is a well-known mechanical model (Kratochvil 2004), but it does not natively consider the degradation or seasonal fluctuation factor. As pointed by Pierro 2017, this is not an issue if the panels are of crystallin's technology, but it can lead to significant decreasing prediction performance with time if the panels are thin films. In such case, some corrective factors have to be introduced, as it is done in the SAM tool.

The direct approach does not rely on an explicit irradiance calculation. Instead, a statistical model predicted electrical production based on the photovoltaic power plant production's historical dataset and contextual data. There is a wide range of statistical models, from simple persistent model to complexes hybrid neuronal network. Each of those models have strong points and weakness (see Das 2018 extensive review with pertinent consideration to available data and forecast horizon). Note that simple models based on persistence assumption are commonly used as control models (see Figure 17). They can require a limited amount historical data-set, while they may allow acceptable accuracy (Bossavy 2013).

Finally, some hybrid approach can be done. As an example, a more accurate prediction can be achieved by using a correction factor to the mechanical model's output. This correction factor is predicted by a statistical model based on an historical data-set of observed mechanical model's predictions errors (Gao 2016).

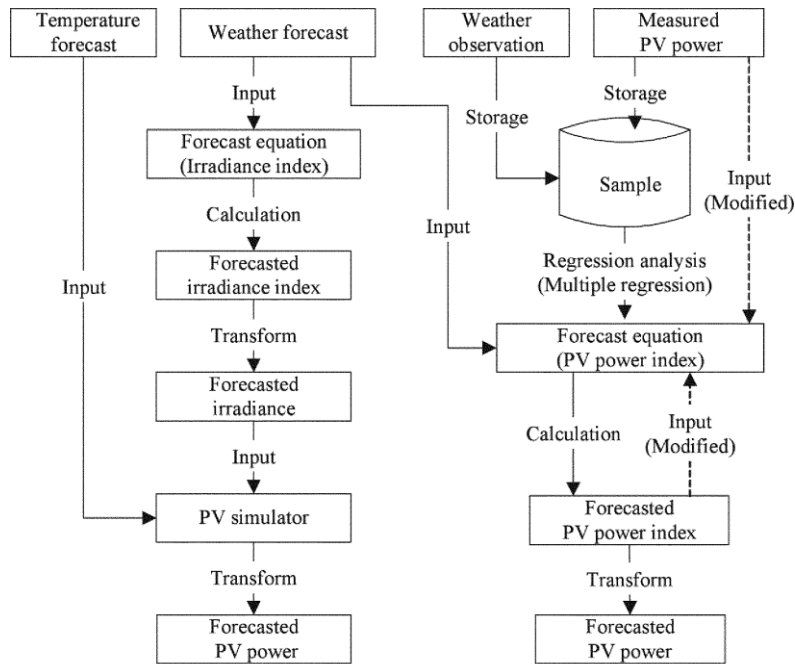


Figure 53: Indirect (left part) and direct (right part) approaches side by side illustration (from Kudo2009)

### Prediction’s performances

Several studies compare both approaches. Even if several comparative studies (Pierro 2017, Kudo 2009) and reviews (Das 2008) point a better prediction for direct models, both approaches share comparable range of precision.

To provide some guidance, about 15% root-mean-square error (RMSE) compared to actual electricity production can be expected. But this is a rough estimation, and the actual prediction error can vary significantly from about 4% (Wang 2017) to 30 % RMSE (Kudo2009) depending of both models (see Figure 17 from Pierro 2017) and context. In this regard, the forecast’s horizon (see Bocquet 2016) and the weather data-set quality (as pointed by Kudo 2009) have a strong impact on model’s prediction accuracy.

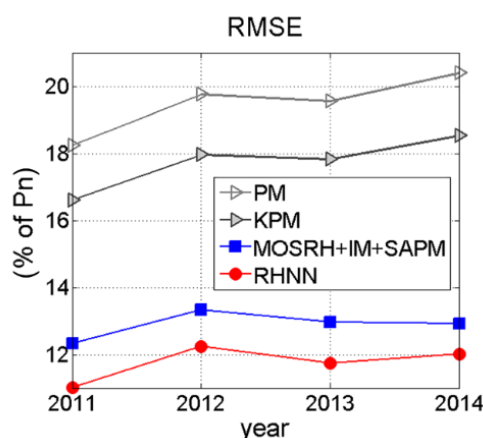


Figure 54: Direct (red) and indirect (blue) performances comparison (from Pierro2017)



## C.2.2 Existing tools and software

A broad variety of solutions exist on the market, from advanced simulation software<sup>21</sup>, to irradiance short term forecast online services<sup>22</sup>. But from the currently available information, the most suitable models/tools for this module seem to be PVSIG<sup>23</sup> (from JRE) or SAM<sup>24</sup> (from NREL). Indeed, those tools based on indirect mechanical models:

- Are easy to use even for non-simulation/modelling/photovoltaic specialists.
- Allows several setup configurations (solar tracking, batteries, on & off grid connection).
- Provide easy to use and up to date panel's technologies specifications (crystalline, thin film etc).
- Provide irradiance data-base (for typical year prediction) with fine temporal resolution (up to hours).
- Provide optimal orientation recommendations for fixed panels.
- Can take neighbourhood shadows into consideration.
- Have extensive documentation (from tutorials to technical reports and scientific papers).

Beside those common features, one can note that:

- PVGIS allows calls through API while SAM is an executable software (with available Software Development Kit (SDK)). PVGIS is based on indirect mechanical model, allows easy photovoltaic production prediction for several setup configuration.
- As both are related to the National Renewable Energy Laboratory (NREL), SAM is natively linked to the National Solar Radiation Database (NSRD), limited to USA records. But the European Joint Research Centre (JRC) and RENE have already started sharing data and importing European irradiance historical record into SAM should be possible.
- SAM provide advanced modules, from technical features (e.g. multiple simulation runs for parametric and sensitivity studies) to financial features (e.g. calculates depreciation period, cost considerations and economic incentives). SAM allows photovoltaic production prediction, and other annex module for power plant sizing and piloting.

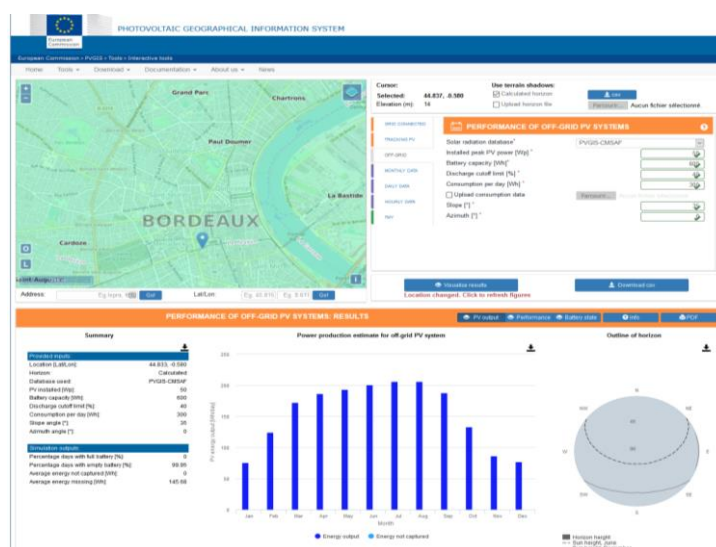


Figure 55: PhotoVoltaic Geographical Information System screenshot

<sup>21</sup>Examples: TRNSYSM: <http://www.trnsys.com/>, HOMER: <https://www.homerenergy.com/>

<sup>22</sup>Examples: <http://steady-sun.com/>, <https://solargis.com>, <https://solarwebservices.ch/>

<sup>23</sup> <http://re.jrc.ec.europa.eu/pvgis.html>

<sup>24</sup> PVWatts is an online module for basic calculation <https://pvwatts.nrel.gov/index.php> whereas SAM is the complete solution <https://sam.nrel.gov/>

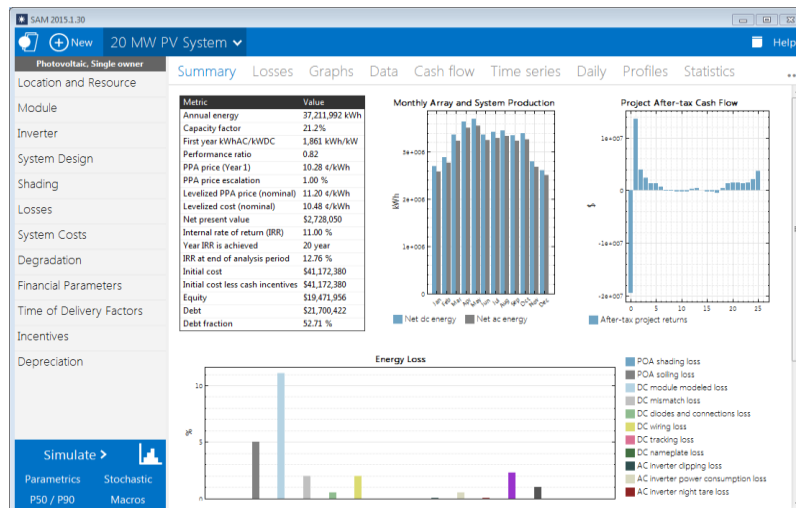


Figure 56: System Advisor Model (SAM) screenshot

## C.4 State of the art – Hinterland multimodal transport model

### C.3.1 Literature review

Some good literature already exists in transport modelling (Tatineni 2005, Dimitrijević 2012, Comi 2010, Beuthe 2000). This literature will need a deeper investigation and will be added in the next version of this deliverable.

### C.3.2 Existing tools and software

There are a lot of different software and tools working on multimodal transport and modelling, but nothing strictly related to freight transportation “from and to” medium and small ports. Most of them are focused on city premises and on persons transportation.

#### PTV Visum<sup>25</sup>

One of the world’s leading traffic planning software designed for transport planners to empower cities. It consistently models all road users and their interactions and has become a recognized standard in the field of transport planning. Transportation experts use PTV Visum to model transport networks and travel demand, to analyse expected traffic flows, to plan public transport services and to develop advanced transport strategies and solutions.

#### WOLF (HUPAC)<sup>26</sup>

WOLF is the Hupac platform to manage all phases of combined transport, from booking to collection, from tracking & tracing to info on any hiccups along the way. WOLF can be accessed on any device (PC, smartphone and tablets) and using any browser (Chrome, Firefox, Safari, Internet Explorer, etc.). WOLF, acronym of Web Oriented Logistics Framework, is the portal that gathers all the data and applications our customers need to manage their shipments in a simple and fast way. There are also many functions for our partners (terminals,

<sup>25</sup> <http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/>

<sup>26</sup> <http://www.hupac.com/EN/Platform-WOLF-9d39b000>

railway undertakings and wagon workshops) letting them manage traffic flows more easily. With WOLF it is possible to: 1) specify who, within their own organisation, shall access the various functions, 2) book shipments; 3) create standard forms for routine booking, 4) access tracking & tracing tools, 5) view shipments at the terminal, 6) specify the driver authorised to collect a shipment from the terminal, 7) view shipment statistics, etc. WOLF also offers a CO<sub>2</sub> calculator that can be customised to the traffic volumes of individual customers. The system performs an immediate comparison with road transport and produces a certificate directly downloadable and printable in PDF. This software is not free and it is not covering pilots needs, especially for what concerning air pollutants emissions

### TMS (Generix Group)<sup>27</sup>

It's a Transport Management and Efficiency software with the aim to: keep administrative charges low, optimize routes, pool resources. With this software it's easier to reference new carriers, quickly open new destinations, manage the multi-modal, pooling and urban logistics. This software sounds good in order to manage fleet and optimise costs, but it's useless to calculate pollutants and as decision maker from an environmental point of view.

## C.5 State of the art – Environmental pollution models

### C.5.1 Quantifying air emissions

Each port should have an Air Quality Environmental Monitoring Program to identify, assess and quantify port's significant air emissions and develop appropriate actions and operational techniques to protect and improve air quality within the port area.

Air emissions occur at different locations of the terminal as a product of various operations, i.e. energy consumption for the purpose of performing port transshipment processes and operations (Table 27).

In general, emissions represent quantification as a function of port activities for evaluating the influence of port terminal processes, as well as a function of vessel in the port, road trucks and railway power demand. Based on the actual consumption of different energy sources over a period of time (working month) for carrying out the core activity of the port terminal, the emission factors calculated by the emissivity of the pollutant in the air were measured using the observed parameters, which are the input data of the model. All mentioned estimated emissions are expressed in kWh multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kWh).

*Table 28: A list of potential indicators of emissions into air*

Indicator symbol	description
CO <sub>2</sub>	carbon dioxide emissions
NO <sub>x</sub>	nitrogen oxide emissions
SO <sub>x</sub>	sulphur dioxide emissions
CO	carbon monoxide emissions
PM	particulate matter emissions
VOC	emissions of volatile organic compounds
GHG (other)	greenhouse gasses emissions

<sup>27</sup> <https://info.generixgroup.com/FR-DownloadproductsheetTMS.html>

The methodology for assessing and quantifying all aspects of the impact of harbor processes on the environment combines emissions that affect the air from different sources during basic port activities.

Emissions into air from ships in the seaport (harbor basin) depend on the type and size of the ship and on the specifics of its energy system. In this sense, we have to differentiate between different sea-going vessels within the port boundaries from harbor crafts within the port boundaries, taking into account various modes (cruise, reduced speed, maneuvering, hoteling). The current approach to calculating the emissions from sea going vessels utilizes energy-based emission factors together with activity profiles for each vessel.

Two different procedures can be used to estimate emissions: based on fuel consumption or engine power. When fuel consumption for each phase is known, then emissions of pollutants can be calculated by using the following equation:

$$E = FC \times EF$$

$$E_i = \sum_p (FC_{e,f,p} \times EF_{i,e,f,p})$$

- $E_i$  = emission
- FC = fuel consumption (kg or tons)
- EF = emission factor (kg/ton),
- $i$  = different types of pollutant,
- $e$  = different engine types (slow, medium, and high-speed diesel, gas turbine and steam turbine)<sup>28</sup>,
- $f$  = fuel type (bunker fuel oil, marine diesel oil/marine gas oil (MDO/MGO), gasoline),
- $p$  = the different phase of operation (manoeuvring, hoteling, cruise).

This procedure is applicable only where detailed information about fuel consumption for each ship/engine type combination in the different navigation phases is available. When fuel consumption per activity phase is not known, then a different methodology is proposed for computing emissions, based on installed power and time spent in different activity phases. Emissions can be calculated from a detailed knowledge of the installed main and auxiliary engine power, load factor and total time spent, in hours, for each phase using the following equation:

$$E_{i,e,f} = \sum_p \left[ A_p \sum_{ec} (P_{ec} \times LF_{ec} \times EF_{ec,i,e,f,p}) \times EEDI \right]$$

- $E_{i,e,f} = E$  = total emission in kg/A
- $A$  = the activity, is the time (h) the ship is cruising, manoeuvring or hotelling; time can also be calculated as the ratio between distance (km) and speed (km/h);
- $E$  = emission
- FC = fuel consumption (kg or tons)
- EF = emission factor (kg/ton),
- $P$  = the Maximum Continuous Rating, indicates the installed engine power of the ship
- $i$  = different types of pollutant,

<sup>28</sup> Slow speed engines: less than 130 rpm, medium speed engines: between 130 and 2,000 rpm, high speed engines: greater than or equal to 2,000 rpm

- e = different engine types (slow, medium, and high-speed diesel, gas turbine and steam turbine)<sup>29</sup>,
- ec = engine category (main, auxiliary),
- f = fuel type (bunker fuel oil, marine diesel oil/marine gas oil (MDO/MGO), gasoline),
- p = the different phase of operation (manoeuvring, hoteling, cruise),
- EEDI = Energy Efficiency Design Index<sup>30</sup>.

From the moment trucks enter into the port, including the time spent at the port, the use of traffic service equipment, until they exit the port, it is necessary to estimate the amount of air emissions caused by the operation of trucks in the port. The type of fuel consumed by trucks should be taken into account. They are mainly the same power and the same fuel used, so the emission factors are the same, except for those using LNG fuel.

$$E = A \times EF \times N$$

$$A = FC/T$$

- E = total emission in kg/T
- A = the activity
- EF = emission factor (g/kg fuel),
- N = number of trucks,
- T = the working time in the port (h) of a truck within the harbour,
- FC = fuel consumption (g/kWh).

Similarly to road traffic, an estimate of the impact of rail traffic on the air in the port is made. From the moment the train composition enters the port, including its time spent in the harbour, the use of equipment for transport services until it leaves the port, it is necessary to estimate the amount of air emissions caused by the work of locomotives in the port. They are mainly the same power and the same fuel used, so the emission factors are the same, except for those using LNG fuel.

Total emissions within the harbour area, coming from diesel trains, are calculated based on the following:

$$E = EF \times d \times c \times N$$

- E = total emission in kg/T
- EF = emission factor in g/kg fuel
- d = distance of rail transport within the harbour (km)
- c = diesel consumption in kg diesel/km
- N = number of diesel trains
- T = working time in the port (h) of a train within the harbour

### C.5.2 Air pollution dispersion model

To model a phenomenon, two types of approaches can be considered: statistical modelling (empirical) and deterministic modelling (physical).

The first approach uses data describing the system's variables (concentration measurements, emission estimates, meteorological observations, etc.) in an equation as the form of a linear regression, without involving any kind of chemical and physical environmental notions. For example, Baawain and Al-Serih (2014) discuss air

<sup>29</sup> Slow speed engines: less than 130 rpm, medium speed engines: between 130 and 2,000 rpm, high speed engines: greater than or equal to 2,000 rpm

<sup>30</sup> The methodology of EEDI calculation, based on the relative CO<sub>2</sub> emission from ship power system and on the benefit for the society, is defined as a method that can be widely used to evaluate the ships energy efficiency and environmental impact through the Index of Energy Efficiency and Environmental Eligibility.

pollution prediction based on an artificial neural network. The data set they use covered a period of four year with hourly measurement of PM<sub>10</sub>, O<sub>3</sub>, CO, SO<sub>2</sub>, H<sub>2</sub>S, NO NO<sub>x</sub> and NO<sub>2</sub>. They also monitored meteorological parameters simultaneously (wind direction, wind speed, relative humidity and air temperature. Even though they showed good results, the use of such approach required a huge data set and need to be validate for different areas. Considering the difficulties (even unavailability) to retrieve such data in the ports participating in PIXEL, we don't consider this approach as suitable to address small and medium ports' real situation.

The second one is based on the formulation of physical and chemical mechanisms and on the numerical resolution of equations based on physical laws. This equation governs the mechanisms controlling the phenomenon in question. The development of these models therefore requires the most detailed understanding of the processes involved. In some case, e.g. in a marked topographic environment and near the sources, the physical processes involved are both of great complexity and not completely known. A good description of mathematical urban air pollution models can be found in (Moses 1969, Cora 2003, Buske 2012, Johnson 2014).

The fact remains that, at present, purely deterministic models offer results that are relevant to decision-makers, if the boundaries are clearly defined, and their performance is regularly assessed. The following table sums up the both approaches.

Deterministic models	Statistical models
We suppose that we know the physical laws, and that we follow the evolution of variables over time.	We search for statistical relations between predictive (or explanatory) variables of the physics and the variable to predict.
<p>Advantages</p> <ul style="list-style-type: none"> <li>- By design extrapolable.</li> <li>- Spatialization of the forecast.</li> <li>- Universality of the approach.</li> </ul>	<p>Advantages</p> <ul style="list-style-type: none"> <li>- Fast prediction and generally satisfactory.</li> <li>- Implementation more "simple", without integration of physical and chemical laws governing the phenomenon.</li> </ul>
<p>Drawbacks:</p> <ul style="list-style-type: none"> <li>- Quantity, quality and diversity of data to provide to the model (emissions, wind fields, boundary conditions, topography ...).</li> <li>- Difficulty going down at very fine scales (local under 1 cm) and in marked topographic environments (strong slopes).</li> <li>- Laws governing different phenomena at these scales, still poorly known today.</li> </ul>	<p>Drawbacks:</p> <ul style="list-style-type: none"> <li>- Need a good documented database.</li> <li>- Provide little explanatory information (Black Box).</li> <li>- More difficult to extrapolate for prospective analysis (use in the domain already observed).</li> </ul>

Despite the difficulty of implementing deterministic models and the technical risks that are linked with (Dimov 2004, Loague 1998), we are moving towards the choice of deterministic model in the context of PIXEL. There are several reasons for this: 1) we want to set up models that can be replicated in different ports, 2) we do not have the necessary database to use statistical models, 3) we want explanatory models.

Deterministic models fall into three categories according to their calculation approach: Eulerian, Lagrangian, and Gaussian models. In a simplified way, these models ask for different sources (sources of pollution, geography, meteorology, etc.) as data inputs. They solve the equations governing atmospheric phenomena and give a mapping of pollutants and establish forecasts.

The Eulerian approach describes the distribution of a substance or a molecule, in a fixed system, according to the characteristics of this system. The principle of the Lagrangian approach consists in following a substance emitted at the source. Eulerian models discretize the mesh atmosphere in 3D. They are also called grid patterns. Lagrangian models are also called trajectory (or plume) models because they solve a system of equations in a referential related to the displacement of a column of air in the path of a plume. The air column moves according to the meteorological conditions (usually pre-calculated or measured, unlike the Eulerian models) considering simple transformation processes, such as linear chemical reactions and deposition.

These two types of models have the advantages of a complete resolution of the equations, an accurate modelling of turbulence and consideration of complex phenomena. If the meshes of study are fine, then these models offer a better representation of the physics. Thus, the main drawbacks lie essentially in the fact that spatial scales are often limited. The computation times depend on the complexity of the model used, the spatio-temporal resolution chosen by the user, and the calculation means implemented. Generally, 3D models require supercomputers and parallel computation on several processors, which does not make them easily accessible. In addition, these models are very sensitive to various parameterizations and input data. Finally, Eulerian and Lagrangian models require very precise knowledge for their use and design. For this reason, we think that they are not adapted at all to be used in the PIXEL framework and that we should consider the last type of deterministic model.

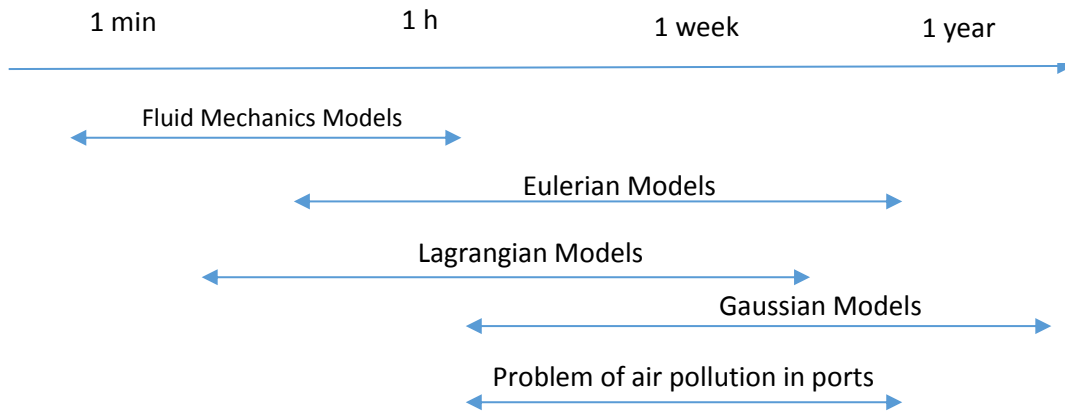


Figure 57: Typology of air dispersion models

Gaussian models (ADMS, AERMOD, ARIA Impact, etc.) are the most used ones to model air quality near areas close to sources of pollution (Lonati 2010, Gibson 2013). The principle of Gaussian atmospheric dispersion is based on a simplified mathematical description of the dispersion equations of a substance in the air. At the base, the substance is dispersed by the sole action of the fluid that carries it, the air. Then the transport and the diffusion will intervene by the action of the wind and the mechanical and thermal turbulence. In other words, this type of model considers that a specific emission (a plume) is dispersed in width, especially since the direction of the wind varies (strong standard deviation), and in height, especially as the air is unstable. The purpose of these equations is to determine the concentrations of the substance according to parameters such as emissions, weather conditions, or other parameters related to the earth's surface (roughness and land use, for example). Generally, a weather processor is integrated with the Gaussian models, which makes it a single software, relatively easier to exploit.

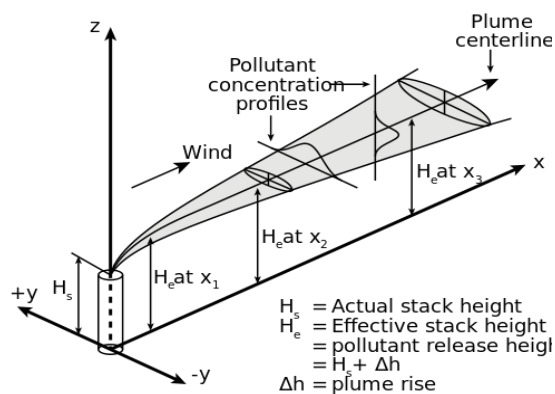


Figure 58: Schematic figure of a Gaussian plume.31

This Gaussian approach is very inexpensive in terms of calculation time (comparing the Eulerian or Lagrangian approach). So, it is possible to multiply the number of simulations carried out and have averages and statistics established on annual or multi-year meteorological databases.

<sup>31</sup> <http://elte.prompt.hu/sites/default/files/tananyagok/AtmosphericChemistry/ch10s03.html>

In return, the parameterizations of the equations are simple, which leads to sometimes rudimentary approximations of some cases (such as the effect of the relief or the buildings, which can have significant influence on dispersal, especially on a small scale). In a first step for the air pollution dispersion prediction, we will use dispersion Gaussian model in PIXEL.

### C.4.3 Noise dispersion model

The Good Practice Guide on Port Area Noise Mapping and Management that has been developed by the partners of the NoMEPorts (Noise Management in European Ports) initiative is a very good starting point to cover all the aspects that relate to modelling noise dispersion.

As stated in this report and showed in Figure 54 the complexity of port's infrastructure and lots of different activities in port lead to many sources that may contribute to the ambient noise of a port area agglomeration. That is why the first step is to mapped noise inside the port to provide the port authorities with the basic information to identify source of noise.

Some previous EU Projects such as HARMONOISE and IMAGINE<sup>32</sup> (Salomons 2011, Ecotiere 2012) was entirely focused on producing a new EU methodology for predicting environmental noise mapping.

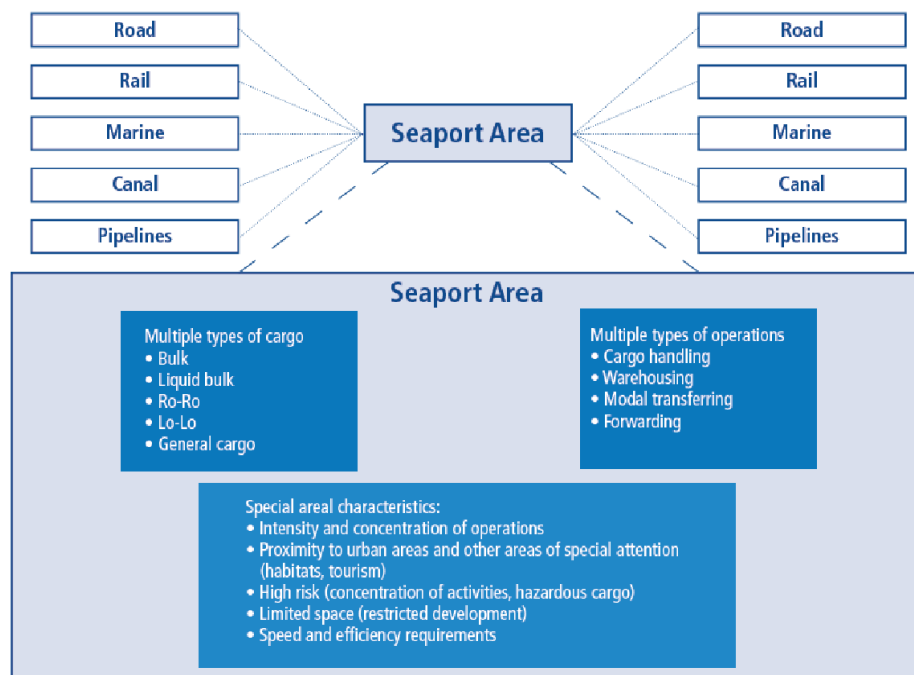


Figure 59: Seaport area characteristics

According to NoMEPorts, the following step should be respect when modelling noise in ports:

- Definition of geographical boundaries for the noise studies should include:
  - The port area where the noise is generating.
  - Residential and other noise sensitive neighbouring areas influenced by the port.
  - Areas Between the port area sources and the neighbouring noise sensitive areas.
  
- Definition of noise source boundaries

<sup>32</sup> <https://cordis.europa.eu/project/rcn/73857/reporting/en>



What is included? E.g. do we include the noise generated by the traffic (roads, railways, air traffic). The recommendation is to first start with a representative picture of the general noise situation in the ports and then try to solve the issue of the relative contribution of different sources.

- Definition of the port area noise mapping
  - Selecting the appropriate calculation methods
  - Collecting geographical information:
    - Spot heights and contours
    - Residential and industrial buildings
    - Other obstacles in the study area (e.g. containers' formations)
    - Location of noise sources
    - Location of noise sensitive areas
    - Identification of surface characteristics of ground
  - Identifying and the modelling noise sources (noise data collection is required)
  - Setting calculation parameters

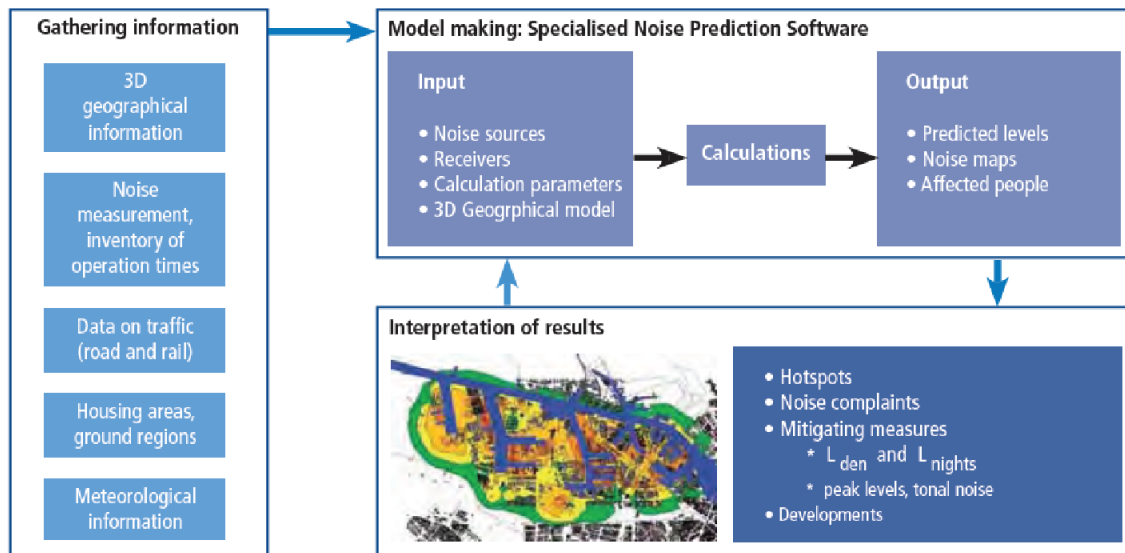


Figure 60: General schematic function of noise prediction NoMEPorts

NoMEPorts also highlight some lessons they have learned about noise data collection:

- Noise data collection can be a time-consuming exercise. It is necessary to get an overview over the input data requirements and availability.
- Gaps within the noise data can be filled by default value or following experts' advice.

In order to run a noise mapping software some first parameters must be set:

- Define the grid on which the calculation will be performed
- Define meteorological data: average of temperature, relative humidity, atmospheric pressure, wind direction and speed.

Noise calculation may be time consuming depending on the total number of noise sources and physical features to calculate. Some techniques could be used in order to reduce the computational time:

- Applying a fetching radius: a distance limit after which noise sources are not taken in considerations

- Reduce of the number of sources in use replacing complicated noise sources networks with simpler ones.

As this analysis of sound propagation models in industrial environments shows, the prediction of sound propagation and noise mapping are complex both in terms of physical modelling, model implementation, use and analysis of results. In addition, the step of identifying sources of noise pollution is an essential step and requires a lot of data.

## C.5.4 Existing tools and software

### Air dispersion modelling

#### **AEROMOD<sup>33</sup>**

According to our knowledge the most well-known and widely used models are the U.S. EPA air dispersion models. There are basically two models that are most often used and those are the steady-state AERMOD model and the dynamic CALPUFF model.

The AERMOD atmospheric dispersion model is an integrated modelling system comprised of three modules. The modules are as follows:

- A steady-state dispersion model designed for short-range (up to 50 kilometers) dispersion of air pollutant emissions from stationary industrial sources.
- A meteorological data module (AERMET) which calculates atmospheric parameters needed by the dispersion model, such as atmospheric turbulence characteristics, mixing heights, friction velocity, Monin-Obukov length and surface heat flux.
- A terrain module (AERMAP) which addresses the relationship between terrain features and the behaviour of air pollution plumes. It generates location and height data for each receptor location. It also provides output which is used as an input by the dispersion model to simulate the effects of air flowing over hills or splitting to flow around hills.

AERMOD also includes PRIME module (Plume Rise Model Enhancements) which is an algorithm for modelling the effects of downwash created by the pollution plume flowing over nearby buildings.

#### **CALPUFF<sup>34</sup>**

CALPUFF is an advanced, integrated Lagrangian puff modelling system for the simulation of atmospheric dispersion of pollutants.

The model has been adopted by the United States Environmental Protection Agency (EPA) in its Guideline on Air Quality Models as a preferred model for assessing long range transport of pollutants for near-field applications involving complex meteorological conditions. The system is also an integrated one and it consists of three main components and a set of preprocessing and postprocessing programs. The main components are the following:

- The CALMET component which is a diagnostic 3-dimensional meteorological model.
- The CALPUFF component (the actual air quality dispersion model).
- CALPOST as the postprocessing package.

In addition to these components, there are numerous other components and processor which can be used to prepare the input data. The input data needed are emission data, land use and terrain data and meteorological data. The CALPUFF model is designed to simulate the dispersion of buoyant, puff or continuous point and area

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<sup>33</sup> <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod>

<sup>34</sup> <http://www.src.com/>

pollution sources as well as the dispersion of buoyant, continuous line sources. The model also includes algorithms for handling the effect of downwash by nearby buildings in the path of the pollution plumes

## Noise dispersion modelling

### **CORMIX<sup>35</sup>**

CORMIX is a US EPA-supported mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges. The system emphasizes the role of boundary interaction to predict steady-state mixing behaviour and plume geometry.

### **I-Simpa<sup>36</sup>**

I-Simpa is a graphical user interface (GUI) developed to host three-dimensional numerical codes for the modelling of sound propagation in complex geometrical domains. Although I-Simpa is well adapted for energetic models (ray-tracing, sound-particle tracing, theory of reverberation...), it can be extended to use ondulatory approaches. I-Simpa alone is not a calculation software but is equivalent to a pre and post-processor for acoustic codes. One or more numerical codes must be added in order to obtain a fully functional system. At the present time, I-Simpa is delivered with two codes (TCR based on the classical theory of reverberation and SPPS based on particle tracing approach). Classical applications are room and building acoustics, environmental noise and industrial noise, but it can be easily extended to other applications concerning the sound propagation in 3D environments (interior of vehicle, sound in cavities...). I-Simpa has been initially developed as a research tool (i.e. for research laboratories) but can also be a very efficient tool for a professional/commercial use, as well as for education.

### **NoiseModelling<sup>37</sup>**

NoiseModelling is a plugin of the OrbisGIS software (an open-source geographic information system) that is able to produce noise maps of cities, according to the French standard method for the road noise emission and using the NMPB method for the sound propagation. The noise calculation method implemented within the NoiseModelling plugin is based on the standard French method called NMPB 2008, as a reference method to be used under the Directive 2002/49/EC relating to the assessment and management of environmental noise (Read More). Most of the algorithms within the NoiseModelling plugin, mainly for the calculation of the sound propagation, are based on spatial analysis methods which allow to optimize and to reduce the complexity of the sound propagation path search in urban areas. Each part of the computation process has been split into several SQL functions thanks to the H2GIS database available within OrbisGIS. This open tool-box helps the user to produce noise maps beyond the limitation of a monolithic computation software. However, the GIS environment allows to produce noise results with a high level of graphical representation, by coupling if necessary with other geospatial databases such as demographic data. For example, using GIS analysis methods, the user can easily compute a map of population exposure.

### **Predictor-LimA<sup>38,39</sup>**

The Predictor-LimA Software Suite, developed by Brüel & Kjær Sound & Vibration Measurement A/S, is the complete solution for all environmental noise projects. The LimA system provides the tools to fully integrate

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<sup>35</sup> <http://www.cormix.info/>

<sup>36</sup> <http://i-simpa.ifsttar.fr/>

<sup>37</sup> <http://noise-planet.org/noisemodelling.html>

<sup>38</sup> <https://www.softnoise.com/pd/predictor.html>

<sup>39</sup> <https://www.emsbk.com/predictor-lima/>

environmental noise predictions in other Geographical Information Systems (GISs). Predictor and LimA use LimA's state-of-the-art calculation cores, which have been independently proven to be the fastest calculation cores available for Calculation of Road and Traffic Noise (CRTN) calculations. LimA calculation cores have a huge capacity, high calculation speed and support 64-bit systems, for even the most demanding tasks, providing results quickly while reducing your investment in computing power.

The version used for the needs of the PIXEL project was Predictor – LimA Standard (Type 7810 - G). Apart from the “Standard” configuration, it also comes in Advanced, Plus, Basic Plus and Basic Standard configurations. The Standard version supports almost all of the available options that the software offers, except the calculation with more than two calculation cores. As the calculation with four, eight or more cores is needed only for the very large models, it was decided that for the use in the project, the version with two calculation cores is good enough.

# Appendix D – Scientific paper published by WP4 partners

In this appendix, readers will find abstracts of scientific papers that have been accepted for publication in conference proceedings or in a journal paper.

The following article has been accepted and presented by MEDRI in the 8<sup>th</sup> International Conference on Maritime Technology, Rijeka, November 2019.

## **NOISE POLLUTION – INTRODUCTION TO THE STATE OF THE RESEARCH AND THE IMPLEMENTATION IN THE HORIZON 2020 PROJECT PIXEL**

**Stjepan Piličić**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, stjepan.pilicic@medri.uniri.hr*

**Luka Traven**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, luka.traven@medri.uniri.hr*

**Teodora Milošević**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, teodora.milosevic@medri.uniri.hr*

**Igor Kegalj**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, igor.kegalj@medri.uniri.hr*

**Ante Skoblar**, *Department of Engineering Mechanics, University of Rijeka, Faculty of Engineering, ante.skoblar@riteh.hr*

**Roberto Žigulić**, *Department of Engineering Mechanics, University of Rijeka, Faculty of Engineering, roberto.zigulic@riteh.hr*

### **ABSTRACT:**

Noise pollution is a significant factor in the modern world. There are many researches dealing with the noise modelling, differing in their purpose, studied influence and the scope of the research, either in geographical terms or in the terms of studied noise sources. The objective of this paper is to give insight in the current state on the field of negative influence that noise has on the environment and/or human health. Special attention was given to the influence that ports' noise pollution has on the surroundings, both on the population and on the environment. Within the influence on the environment, underwater noise, which is often excluded when the main priority is the influence on general population, was also included. As it is one of the main tools for analysing the influence of noise, several examples of assessing the influence of the noise using noise maps are presented. Several objectives of the EU Horizon 2020 project (PIXEL), dealing with the reduction of ports' pollution, were covered. The segment of the project dealing with the noise is linked with the previous achievements, which forms the basis to give some guidelines for the further research of the noise influence on the environment.

**Keywords:** *noise pollution, port pollution, environment, noise maps*

The following article has been accepted and presented by MEDRI in the 8<sup>th</sup> International Conference on Maritime Technology, Rijeka, November 2019.

## AIR POLLUTION DISPERSION MODELING IN PORT AREAS

**Teodora Milošević**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, teodora.milosevic@medri.uniri.hr*

**Lado Kranjčević**, *Department of Fluid Mechanics and Computational Engineering, University of Rijeka, Faculty of Engineering, lado.kranjcevic@riteh.hr*

**Stjepan Piličić**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, stjepan.pilicic@medri.uniri.hr*

**Marko Čavrak**, *Teh-Projekt Oprema d.o.o., Rijeka, mcavrak@gmail.com*

**Igor Kegalj**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, igor.kegalj@medri.uniri.hr*

**Luka Traven**, *Department of Environmental Medicine, University of Rijeka, Faculty of Medicine, luka.traven@medri.uniri.hr*

### ABSTRACT:

For the last couple of decades, environmental protection awareness within port areas is gaining ever more importance. Ports can have a tremendous impact on the environment, especially in terms of air pollution. The main pollution sources are various port activities such as road and rail traffic, cargo handling and marine vessel operations. Air quality models can be of great help in estimating the effect on the ambient air quality from one or more sources emitting pollutants to the atmosphere. One of those models is the widely used Gaussian Plume dispersion approach. Based on existing measurements and port activity data, models can simulate the dispersion of air pollutants caused by activities and operations taking place within the port. By using historical data, they can simulate the current state of the air quality in the port and with the help of weather predictions simulate possible future situation. Simulations can assist the port manager/operator in the decision-making process in order to optimize various activities within the port and minimize their impact on the environment. One of the main objectives of the Horizon 2020 Project PIXEL (Port IoT for environmental leverage) is the deployment of environmental pollution models which can aid in the decision-making processes within the port domain. This paper reviews the current advances in the field of air pollution modelling with a special emphasis on port scenarios.

**Keywords:** *environmental engineering, Gaussian Plume dispersion model, air quality, air pollution, seaports*

The following article have been accepted and presented by CATIE in the Maritime Transport Conference, Rome, September 2019. Readers can find all information regarding the conference and the Agenda [here](#). The PIXEL contribution is [here](#) (presentation) and [here](#) (paper).

## **SMALL AND MEDIUM PORTS' ACTIVITIES MODELLING: INTRODUCTION TO THE PIXEL APPROACH**

ERWAN SIMON<sup>1</sup>, CHARLES GARNIER<sup>1</sup>, IGNACIO LACALLE<sup>2</sup>, JOAO PITA COSTA<sup>3</sup>, CARLOS E. PALAU<sup>2</sup>

<sup>1</sup>*Centre Aquitain des Technologies de l'Information et Electroniques 1 Avenue du Dr Albert Schweitzer, 33400 Talence, France*

<sup>2</sup>*Universidad Politécnic de Valencia, Cami de Vera S/N, Valencia 46022, Spain*

<sup>3</sup>*XLAB, Pot za Brdom 100 Ljubljana SI-1000, Slovenia*

### **ABSTRACT**

Port activities undeniably have an impact on their environment, the city and citizens living nearby. To have a better understanding of these impacts, the ports of the future will require tools allowing suitable modelling, simulation and data analysis. This challenge is also tied to another current reality: the heterogeneous data coming from different stakeholders converging into ports are not optimally exploited due to lack of interoperability. Thus, the forthcoming research and development initiatives must address these demands from a holistic point of view. PIXEL (H2020-funded project) aims at creating the first smart, flexible and scalable solution reducing the environmental impact while enabling optimization of operations in port ecosystems. PIXEL brings the most innovative IoT and ICT technology to ports and demonstrate their capacity of taking advantage of modern approaches. Using an inter-operable open IoT platform, data is acquired and integrated into an information hub comprised of small, low-level sensors up to virtual sensors able to extract relevant data from high level services. Finally, this hub integrates smart models to analyse port processes for prediction and optimization purposes: (i) a model of consumption and energy production of the port with the aim of moving towards green energy production, (ii) a model of congestion of multi-modal transport networks to reduce the impact of port traffic on the network and (iii) models of environmental pollution of the port to reduce the environmental impacts of the port on the city and its citizens. The main issue tackled by PIXEL is to provide interoperability between these models and allow real integration and communication in the context of an environmental management model. Besides that, PIXEL devotes to decouple port's size and its ability to deploy environmental impact mitigation specifying an innovative methodology and an integrated metric for the assessment of the overall environmental impact of ports.

*Keywords: simulation, algorithms, environment, IoT, environmental impact, interoperability, port activities, port of the future*